Carbon Prices and Inflation in a World of Shocks

Systemically significant prices and industrial policy targeting in Germany

BertelsmannStiftung

Publisher
Bertelsmann Stiftung
Carl-Bertelsmann-Straße 256, 33311 Gütersloh
bertelsmann-stiftung.de

Responsible for content
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Project Manager
Nachhaltige Soziale Marktwirtschaft

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Recommended citation style
Weber, I.; Thie, J.;Jauregui,J.; Teixeira,L.(2024): Carbon Prices and Inflation in a World of Shocks-Systemically significant prices and industrial policy targeting in Germany. Bertelsmann Stiftung, Sustainable Social Market Economies, Gütersloh. https://doi.org/10.11586/2024092

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DOI 10.11586/2024092

ID_2299

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Abstract

Climate change and geopolitical tensions render supply shocks more likely, which can trigger inflation ("shockflation"). Additionally, the EU's reliance upon an emissions trading system as its chief climate mitigation policy can give rise to inflation ("carbonflation"). Through simulations using an input-output price model for Germany, we show that the same systemically significant sectors – those essential for human livelihoods, production and commerce – are particularly vulnerable to both shockflation and carbonflation, if carbon markets are the only policy tool deployed to cut emissions. A total of up to 78 percent of potential carbonflation can be attributed to just six systemically significant sectors. Our findings remain robust under varying assumptions regarding substitution and passthrough effects. The challenge for policymakers is to design policies that combine transformation with stabilization. Enhancing resilience, dampening price volatility and designing green industrial policies for these key sectors can reduce the macroeconomic risks of both carbonflation and shockflation.

Keywords: inflation, supply shocks, climate change, carbon price policy, resilience

1. Introduction

Supply shocks have been widely cited as important drivers of inflation in recent years (Bernanke and Blanchard, 2023, Kilian and Zhou, 2022). Certain sectors have a greater potential to trigger such "shockflation" than others (Weber et al. 2024). Borrowing from the idea of some banks being too important or too connected to fail in the context of financial stability, we consider these sectors as systemically significant (Hockett and Omarova, 2016).[1] The recent bout of shockflation has been unleashed by the emergencies of the COVID-19 pandemic and the war in Ukraine. However, the climate emergency has also been identified as a trigger for shockflation (Batten et al., 2020; Dafermos et al., 2021, Schnabel, 2022). Extreme weather events can disrupt production processes (Dell et al., 2012), reduce overall economic productivity (Burke et al., 2015; Kotz et al., 2024), affect agricultural yields (Anderson et al., 2020), interrupt transportation (Markolf et al., 2019), and undermine the productivity of renewable energy generation and fossil fuel systems (Solaun and Cerdá, 2019). These are just a few examples of climate-induced supply shocks.

While climate change poses a major threat to price stability, CO_2 price policies – particularly when they are market-based and volatile as is the case for the key climate mitigation tool in the European Union – can create additional inflationary pressures (e.g., Brand et al, 2023; Hensel et al., 2024; Konradt et al., 2024),[2] which we term "carbonflation."

Climate change mitigation policies face challenges in an inflationary environment. If central banks respond to shockflation by raising interest rates and governments resort to fiscal austerity, as seen in the eurozone, there is a risk that decarbonization investments will slow down or even halt due to high upfront capital costs in critical areas like renewable energy (Egli, et al., 2018; Schmidt et al., 2019; Kriwoluzky and Volz, 2023). The economic insecurity associated with an austerity response to inflation also bears a political risk by strengthening far-right parties and thus undermining political support for climate change mitigation policies.[3]

In this paper we use input-output simulations to assess which sectors are systemically significant for both shockflation and carbonflation. We expand on the modeling approach developed for the United States by Weber et al. (2024) to provide a sectoral perspective on inflation risks. While most studies analyze the impact of a shock to a single industry or goods market, we simulate shocks to all sectors of the economy and rank them based on their simulated total inflation impact (direct and indirect). Our simulations identify three pathways to systemic significance in shockflation: First,

1 See Kriwoluzky and Volz (2023) for an overview of impacts of climate change on key macroeconomic variables including inflation.

2 Carbon prices' impact on inflation has been the subject of multiple studies. Sometimes referred to as "Greenflation" (Kriwoluzky and Volz, 2023) we prefer "CO_2 prices can affect the supply side by increasing production costs which drive up inflation" (Brand et al., 2023). For the EU, it is estimated that an increase in the ETS price by 10 EUR/tCO_2 increases energy CPI inflation by 0.8 percentage points and headline inflation by 0.08 percentage points (Moessner, 2022). They also increase firms' inflation expectations (Moretti et al., 2023) but have no statistically significant and long lasting impact on investments in renewable energy (Nishigaki, 2023).

3 See, for example, Baccini and Sattler (2023), Fetzer (2019) and Gabriel et al. (2023).

a sector's weight in the Consumer Price Index (CPI), its importance as an input to other sectors (forward linkages), and the sectoral price change. In the simulation of carbonflation, the third pathway is replaced with sectoral emissions intensity and the emissions market, which together determine the carbon price changes.

Germany serves as a particularly interesting case for shockflation due to the 2022 energy crisis. The energy price shock has been the most significant driver of inflation in Germany in recent years (e.g., Pallotti et al., 2023). Germany is also relevant for carbonflation because, in addition to its national carbon pricing policies, it participates in the European Emissions Trading System (ETS1) and will join ETS2 for most sectors under the Effort Sharing Regulation (ESR) starting in 2027. ETS2 will replace the national carbon price. The consequences of this transition for price stability are uncertain. Some experts warn that the prices emerging from ETS2 could be highly volatile, potentially leading to a carbon price shock comparable to the fossil fuel price shock of 2022-2023 following the Russian war in Ukraine (Agora Energiewende und Agora Verkehrswende, 2023; Kalkuhl et al., 2023).

Our paper has three main findings: First, systemically significant sectors for shockflation fall into three categories: essentials for human livelihoods (e.g., food, utilities), essentials for production (e.g., energy inputs), and essentials for commerce (e.g., warehousing and transportation). Five sectors have had an outsized impact on Germany's shockflation following the onset of the Russian war of aggression in Ukraine: Oil and Gas; Electricity, Heating, and Cooling; Food, Beverages, and Tobacco; Agriculture; and Coke and Petroleum products. These sectors were also identified as points of vulnerability for price stability in our analysis using pre-COVID-19 data to determine latent systemic significance. The top sectors with the largest potential and realized inflation impact are robust to a range of assumptions on substitution and passthrough effects.

Second, the sectors with the greatest potential to trigger carbonflation are a subset of those with latent systemic significance for shockflation. Up to 78 percent of carbonflation is driven by six sectors: Real Estate Services; Electricity, Heating, and Cooling; Oil and Gas; Land Transport; Coke and Petroleum Products; and Food, Beverages, and Tobacco.[4] These sectors are both points of vulnerability for inflation due to exogenous shocks and main drivers of carbonflation induced by carbon pricing. The link between shockflation and carbonflation is the high price volatility of fossil fuels and high emissions intensity.

Third, there is major uncertainty around future levels and volatility of carbon prices and, consequently, the magnitude of carbonflation. Using estimates of carbon prices by Pietzcker et al. (2021) to meet EU emission reduction targets, we find that the cumulative inflation impact from 2023 to 2030 ranges from 2 percent (lower bound CO_2 price estimates of EUR 95/tCO_2 for ETS1 sectors and EUR 210/tCO_2 for ETS2) to 4.5 percent (upper bound estimates of EUR 210/tCO_2 for ETS1 sectors and EUR 405/tCO_2 for ETS2). Importantly, these estimates assume no other measures than carbon pricing. Other emissions mitigation measures would likely lower the CO_2 price. Our estimates of carbonflation are consistent with the literature (e.g., Delgado-Téllez et al., 2022; Konradt et al. 2024; Nöh et al. 2020). To put this into perspective, when translated into annual inflation rates the simulated carbonflation ranges from 10 percent to nearly a quarter of the annual ECB inflation target of 2 percent.

Similar to other studies, our simulations assume a linear increase in carbon prices for ETS1 sectors and add a price spike in 2027 for the ETS2 sectors. The cumulative effect of carbonflation could, however, be much greater in situations where carbon prices are volatile and carbonflation triggered by price jumps is not offset by deflation when carbon prices fall, which is likely. Furthermore, a key factor influencing carbon price estimates is the pace at which low-carbon technologies are adopted in the market. High financing costs, driven by high interest rates, can hinder this adoption. This, in turn, can exacerbate carbonflation and increase the uncertainty of these estimates.

Our findings suggest that shockflation and carbonflation are serious macroeconomic risks but can be mitigated by policies targeting sectors with latent systemic significance to enhance resilience to supply shocks, reduce price volatility and implement green industrial policies. In principle, climate mitigation policy can rest on three complementary pillars: 1) standards and engagement, 2) markets and prices, and 3) strategic investments (Grubb et al., 2023). Carbon prices fall into

4 Agriculture drops out of the top ranks in our carbonflation simulation because it is not part of ETS and will not be part of the ETS2.

the second category. Targeting policies in the first and third pillars to systemically significant sectors can reduce their emission intensity, vulnerability to carbon price volatility, and the risk of carbonflation.

The rest of the paper proceeds as follows: In the next section, we introduce our modeling approach. In the third section we identify systemically important prices in the recent German shockflation using both long-run price volatilities and the recent energy crisis to calibrate our simulation of price shocks. In the fourth section, we illustrate the uncertainty around the magnitude of carbonflation and analyze the extent to which carbonflation is driven by systemically important prices in our simulations. In the fifth and final section, we discuss sectoral policy conclusions.

2. Approach to input-output simulations

a. The general model

For the purposes of this study, we implemented simulations of the inflation impact of sectoral price shocks using a Leontief price model for the German economy. We considered two kinds of shocks: (1) an exogenous output price change of an individual industry to simulate shockflation, and (2) a CO_2 price policy that increases the costs of production across all industries to simulate carbonflation. Our modeling strategy thus expands on Weber et al. (2024) by incorporating two new features. First, we directly account for import price changes. Second, we bridge the input-output table with the actual CPI instead of using a synthetic version, thereby improving the measurement of inflation impacts.

The starting point is the basic identity showing that the value of output for each industry equals the value of domestically produced inputs, plus the value of imported inputs, plus value added. Value added consists of profits (gross operating surplus), wages (workers' compensations), and net taxes. Expressing this identity for all industries with matrix notation, we get:

$$\hat{X}P = \hat{X}A'P + M + V \qquad (1)$$

Where $\hat{X}$ is a diagonal matrix of gross output, P is the vector of unit prices, A is the matrix of domestic direct requirements, M and V and are the vectors of imports of intermediate goods and value added, respectively. Pre-multiplying them by $\hat{X}^{-1}$ and solving for P retrieves the basic equation of the Leontief price model:

$$P = (I\text{-}A')^{-1}(m+v) \qquad (2)$$

Here, *m* and *v* represent vectors of the ratios of imported inputs and value added per unit of output for each sector. Equation (2) shows how the unit prices of all industries depend on each other through their input-output relationships (expressed in matrix A') and the prices of primary inputs (imported inputs and value added). More specifically, matrix $(I - A)^{-1}$ is the transpose of the Leontief inverse matrix and its elements represent the *direct and indirect* requirements of domestic inputs to produce one unit of output for each sector.

b. Exogenous price shocks and inflation impact

To simulate price shocks in individual industries, we set the price of the targeted industry as exogenous. This means the output price is independent of other goods' prices, wages, profits, and import prices. Additionally, sectors within the categories of "commodities" and "rent" that do not generally follow a cost-plus markup pricing logic, such as Coal, Oil and Gas, Mining and Quarrying, and Real Estate Services, are also set as exogenous in all simulations. Let E represent the subset of endogenous sectors and X the subset of exogenous sectors. In equation (2), individual industry prices will change due to changes in v and m. We can now write an alternative version of equation (2)[5] as:

$$P_E = (I\text{-}A'_{EE})^{-1}A'_{XE}P_X + (I\text{-}A'_{EE})^{-1}(m_E + v_E) \qquad (3)$$

Where A_{EE} and A_{XE} are partitions of the original domestic requirements matrix A.[6] This equation shows that endogenous sectors' prices depend on exogenous sectors' prices.[7] Let ΔP_X and ΔP_M represent the price change of the exogenous domestically produced goods

5 The derivation of this equation and an explanation of each term can be found in the appendix.

6 The first subindex represents the rows and the second the columns that are kept from the original matrix A.

7 The degree of dependence has two components: the extent to which exogenous sectors enter as inputs of endogenous sectors (represented by matrix A_{XE}) and the general input-output interdependence of endogenous sectors (represented by matrix A_{EE}).

and of the imported exogenous goods, respectively. We assume $\Delta P_X = \Delta P_M$, meaning the price change is the same for domestic and imported goods.[8] The price change of imported inputs (ΔP_M) modifies the share of imported inputs in gross output (Δm_E). The prices of endogenous sectors will change according to the following equation:

$$\Delta P_E = (I\text{-}A'_{EE})^{-1} A'_{XE}\, \Delta P_X + (I\text{-}A'_{EE})^{-1} \Delta m_E \qquad (4)$$

This equation indicates that a change in the domestic and import prices of one sector generates a price change in the endogenous sectors given by ΔP_E. The element *i* of this vector shows the percentage change in the price of the industry *i* will be caused by the price change ΔP_X and the equivalent import price change. To derive a single measure of inflation generated by a price shock, we calculated a weighted average of the vectors of price changes, termed the "inflation impact." This refers to the price increase of an average national consumption basket brought about by an initial price change.

We can divide this total effect into its direct and indirect components. Formally, for an initial shock ΔP_X, we have:

$$IP_{tot} = \sum_{i \neq x} w_i\, \Delta P^i_E + w_X\, \Delta P_X \qquad (5a)$$

$$IP_{ind} = \sum_{i \neq x} w_i\, \Delta P^i_E \qquad (5b)$$

$$IP_{dir} = w_X\, \Delta P_X \qquad (5c)$$

The subscripts on the left of the equations refer to the total, direct and indirect inflation impact. w_i is the share of industry *i* in the CPI, and ΔP^i_E is the price change for the endogenous sector *i* (the subscript x refers to the consumption share of the exogenous industries). This means that our measures of inflation impact can be interpreted as the percentage increase in the CPI induced by a price shock in any particular sector. The direct effect refers to consumers paying more for the final goods produced by the industry where the original price shock occurs. The indirect inflation impact reflects the extent to which other firms use the output of the shocked industry as inputs, which raises their production costs and, consequently, the final price of their products.

The actual price shocks (ΔP_X) used to simulate the inflation impact of sectoral cost increases and identify systemically important sectors are:

- Sectoral price volatility from 2000 to 2019 (i.e., the standard deviation of yearly price changes during this time period), capturing the latent tendency of prices to move in a sector.
- The annual price change from Q3 2021 to Q3 2022 (i.e., the peak price increases following the onset of the Russian war of aggression against Ukraine).

c. Carbon prices

To simulate the inflation impact of a carbon price policy, we calculated the vector of the carbon price paid per unit of output for each industry (τ) by applying the carbon price $\hat{\theta}$ (a diagonalized vector with the price of a unit of CO_2 emitted per industry) to the carbon intensity vector (c). *c* shows how much CO_2 each industry generates per unit of output:

$$\tau = \hat{\theta}\, c \qquad (6)$$

We partition τ into endogenous sectors (τ_E) and exogenous sectors (τ_X), and add τ_E and τ_X to their corresponding primary cost vector (valued added plus imports). The price change for exogenous sectors (ΔP_X) from carbon pricing is the respective value of τ_X, while the price change for endogenous sectors is given by:

$$\Delta P_E = (I - A'_{EE})^{-1} A'_{XE}\, \tau_X + (I - A'_{EE})^{-1} \tau_E \qquad (7)$$

Stacking the vectors of price changes (ΔP_E and ΔP_X) results in the final vector of price changes, denoted as ΔP_{CO2}. The overall inflation impact and the carbon price revenue depend on the carbon price and carbon intensity.[9] We perform the simulations similarly to the exogenous

8 For our analysis, we are agnostic about the origin of the shock. This no-arbitrage condition implies that the shock could have originated domestically or abroad, but once it has occurred, domestic and imported prices must move together, so the law of one price holds.

9 This baseline model does not account for household carbon emissions leading to an underestimation of the carbon price inflationary impact. To rectify this, we distribute household emissions that are mainly generated due to heating and private transportation to the sectors where they accrue. We therefore calculate the inflation impact of pricing household emissions independently of our input-output price model, as they do not present indirect effects because they do not correspond to inputs to other sectors. Formally, we add the tax revenue per unit of gross output for the two relevant sectors (Real Estate Services and Land Transport) stemming from household emissions to the sectoral price changes.

price changes described in the previous section, simulating the effect of the CO_2 price *one sector at a time*. In each simulation, only one sector pays the respective CO_2 price. This gives us a measure of the inflation impact of the CO_2 price for each sector. As before, we can divide this total sectoral inflation impact into its direct and indirect components. However, an important difference is that we can sum each sectoral inflation impact to obtain the aggregate inflation impact of the CO_2 price policy as a whole. This aggregate result is the same as if we had assumed that each sector pays its CO_2 price simultaneously. This method allows us to estimate the aggregate inflation impact of a CO_2 price policy and to determine the contribution of each sector to this aggregate inflation.

d. Dynamic substitution effect

So far, we have assumed that production technology remains constant. However, technology upgrading is precisely the purpose of a CO_2 price policy. We therefore relaxed this assumption and incorporated dynamic substitution effects.[10] The dynamic substitution is achieved by modifying technical coefficients (a_{ij}) from the domestic technical requirement matrix A, to reflect a reduction in energy requirements in response to an increase in price. We also consider zero substitution for non-energy inputs (Buns, 2018).

The relative price between energy and the sectoral value added will increase when adding carbon prices. Since value added is exogenous in the baseline input-output price model, this change in the relative price of energy is the change in the energy sector price (defined here as Δp_1). Following Buns (2018) and assuming a scenario of pure technological progress,[11] the effect of the relative increase in the energy price will affect just the energy input technical coefficient (a_{1j}) for any sector j as follows:

$$\Delta a_{1j} = - \frac{\sigma_j \Delta p_1}{1 + \sigma_j \Delta p_1} a_{1j} \tag{8}$$

Where the parameter σ_j shows how the energy technical coefficient reacts to a change in energy prices. The negative sign of Δa_{ij} indicates that producers manage to reduce their use of energy when energy prices increase. For our analysis, σ_j is the elasticity of substitution parameter calibrated to values from the literature.

With this, it is straightforward to calculate ΔA, a matrix capturing the changes in the direct technical coefficients. The following equation derives the inflation impact of the CO_2 price policy when we account for substitution:

$$\Delta P_{CO2} = L'\Delta l + L'\Delta A'p \tag{9}$$

The first term, $L'\Delta l$, is the inflation impact without substitution and is equal to $(I - A')^{-1}\Delta l$, which matches the right-hand side of equation (2). The second term ($L'\Delta A'p$) represents the pure technological progress (or dynamic substitution) effect. Since all the elements of $\Delta A'$ are either negative or zero, all the elements of $L'\Delta A'p$ will also be negative or zero, meaning that the inflation impact will be lower due to the dynamic substitution effect.

e. Data

To implement our simulations of price shocks and CO_2 price policies for Germany, we aggregated the 2019 input-output table (Destatis, 2023a) to align with the emissions data provided by the German Federal Statistical Office (Destatis), resulting in a modified input-output table encompassing 53 sectors. No single table comprising all sectoral producer prices matches the input-output table provided by Destatis. We compiled price data from various Destatis sources to match the input-output sectors. For some sectors, there is no direct match. In these cases, we estimated their prices by creating a sectoral price index compiled from other relevant sectors. At the same time, there is some variation between sectors in the coverage of price data across periods, which is relevant for our measure of sectoral price volatility (see Table B.1 in the appendix). An important contribution of this paper is simulating the effect of price shocks on the actual CPI. This requires aligning the input-output sectors with the Classification of Individual Consumption by Purpose (COICOP) categories. We connected these two classification systems using the consumption interdependence table (Konsumverflechtungstabelle) for 2019, obtained from

10 It is inspired by the “induced technical change” first introduced by Hicks (1932), and it is also similar to what Sylos-Labino referred to as “dynamic substitution” (Sylos-Labini, 1988 and 1995).

11 This means that producers manage to reduce their use of energy without needing to increase their use of any other input.

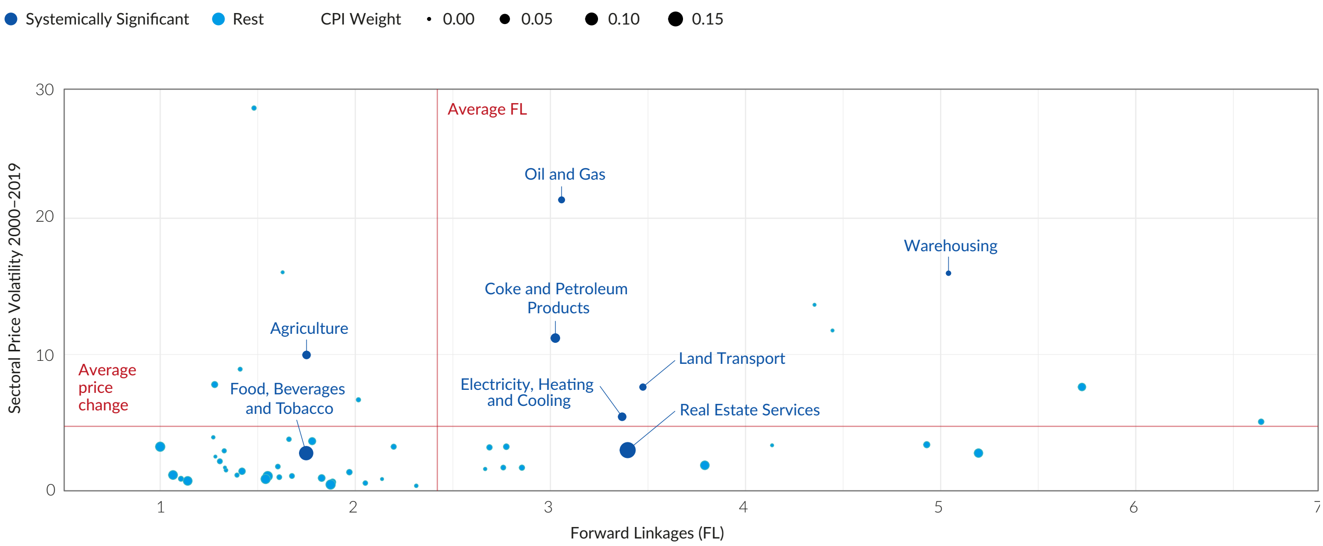
Destatis, thereby enhancing the accuracy of our inflation impact estimations by bypassing assumptions about product-commodity relationships (Jacksohn et al., 2023).

We sourced 2021 greenhouse gas emissions data (measured in CO_2-equivalent) from the environmental economic accounting provided by Destatis (2023a). The table also provides the sectoral emissions that fall under the ETS. Approximately 40 percent of all emissions in Germany were subject to the ETS in 2021. However, the Destatis data lacks precise sectoral emissions for the national carbon pricing system. According to the German emission trading authority (DEHSt), another 306 million tons of carbon emissions were priced nationally in the same year (DEHSt, 2023). To distribute these emissions, we follow Agora Energiewende and Agora Verkehrswende (2023), which report the sectoral shares of emissions that fall under the national emission trading system. As these sectors are listed in the Common Reporting Format (CRF), we employ Eurostat's correspondence table (Eurostat, 2015) to align them with our input-output sectors based on CPA categories. Most of these nationally priced emissions are attributed to private households, while others are allocated to manufacturing or energy industries. Consequently, some sectors' emissions fall under either the EU ETS or the national carbon pricing system. This approach ensures that we closely approximate real-world carbon pricing in Germany while accounting for the bulk of emissions that are indeed subject to a carbon price, amounting to 77 percent of all emissions.

3. Points of vulnerability for "shockflation": systemically significant prices in Germany

In order to identify the sectors that are systemically significant for price stability in the German economy we present two sets of results in this section. First, we use sectoral price volatilities (from 2000 to 2019) as exogenous price changes and simulate their potential inflation impact. This allows us to rank each sector based on its potential impact on inflation. The sectors at the top of this ranking have the greatest potential to generate inflation prior to the recent shockflation episode. In other words, these top-ranked sectors are latent systemic significant. Secondly, we calculate the actual price changes observed during the 2022 shockflation at the peak of the energy crisis in the wake of the war in Ukraine. The top sectors of this ranking played a key role in the recent shockflation episode and realized systemic significance based on our simulations. Most of the sectors with realized systemic significance are also identified as having latent systemic significance.

FIGURE 1 Three channels to systemic significance: Forward linkages, price volatility and CPI weight



Notes: The measure of forward linkages for each industry is represented on the x-axis and is calculated as the sum of the rows in the total domestic requirements matrix, and is given by the x-axis. The y-axis displays the average annual price change of each industry between 2000 and 2019, which we call the "sectoral price volatility". The position of the horizontal and vertical axes marks the price volatility and the average measure of forward linkages across all industries, respectively. Systematically significant industries are highlighted dark blue with their descriptions, while the rest are colored light blue. The size of each dot reflects the sector's weight in the CPI. Data sources: Destatis Input-Output 2019 tables, Destatis price indices.

a. Latent systemic significance

In our model, there are three pathways to systemic significance for inflation: the tendency of prices to move (volatility), the extent to which a sector is directly or indirectly used as an input (forward linkages), and the importance of a sector's output for personal consumption (weight in the CPI) (see Figure 1 for illustration). These three dimensions jointly determine the inflation impact of a price shock to any one sector.

For the United States, Weber et al. (2024) identify three groups of systemically significant sectors: 1) those that provide essentials for human livelihood such as Food, Housing and Utilities, 2) those that provide essential production inputs including energy like Oil and Petroleum Products, and Chemicals, and 3) those providing the essential infrastructure for commerce like Wholesale Trade. Our findings confirm the existence of these three groups of systemically significant sectors in Germany. The rankings of all sectors in terms of latent and realized systemic significance are presented in Table B.2.

Figure 2 shows the latent systemic significance ranking of all 53 sectors in the input-output table according to the inflation impact simulated using the sectoral annual price volatilities in 2000-2019. It shows that there are broadly speaking three brackets of sectors in terms of their inflation impact: The top ten ranks have a clearly outsized inflation impact compared to all other sectors above a threshold of 0.2 percent (ranging from 0.22 to 0.87 percent). Sectors in the next bracket, comprising ranks 11 to 30 have a considerably smaller but still noticeable inflation impact. The third bracket of ranks 31 to 53 are those showing a negligible impact. We classify the sectors in the top bracket as those with latent systemic significance that are most likely to become systemically significant during periods of shockflation.
Sectors with latent systemic significance in Germany fall into the same groups as those for the United States.:

1) Essentials of human livelihood: Agriculture; Food, Beverages and Tobacco products; Real Estate Services; Coke and Petroleum Products; and Electricity, Heating and Cooling (utilities).
All sectors in this group have large weights in the CPI. Agriculture, Electricity, Heating and Cooling, and Coke and Petroleum Products have above average price volatility reflecting the commodity nature of these sectors. The latter two sectors also have high forward linkages, which highlights their relatively importance as inputs into other sectors. The same is true of Real Estate Services, which in Germany includes both residential but also commercial housing. Thus, these three sectors also fall into the next group.

2) Essential infrastructure for commerce: Warehousing; and Land Transport.
All sectors in this group play a crucial role as inputs, given that all industries depend on the circulation and transportation of goods. Warehousing, despite a very low CPI weight due to minimal consumer contact, hardly stands out for its upstream relevance and price volatility, while Land Transport is rendered systemically significant across all three channels.

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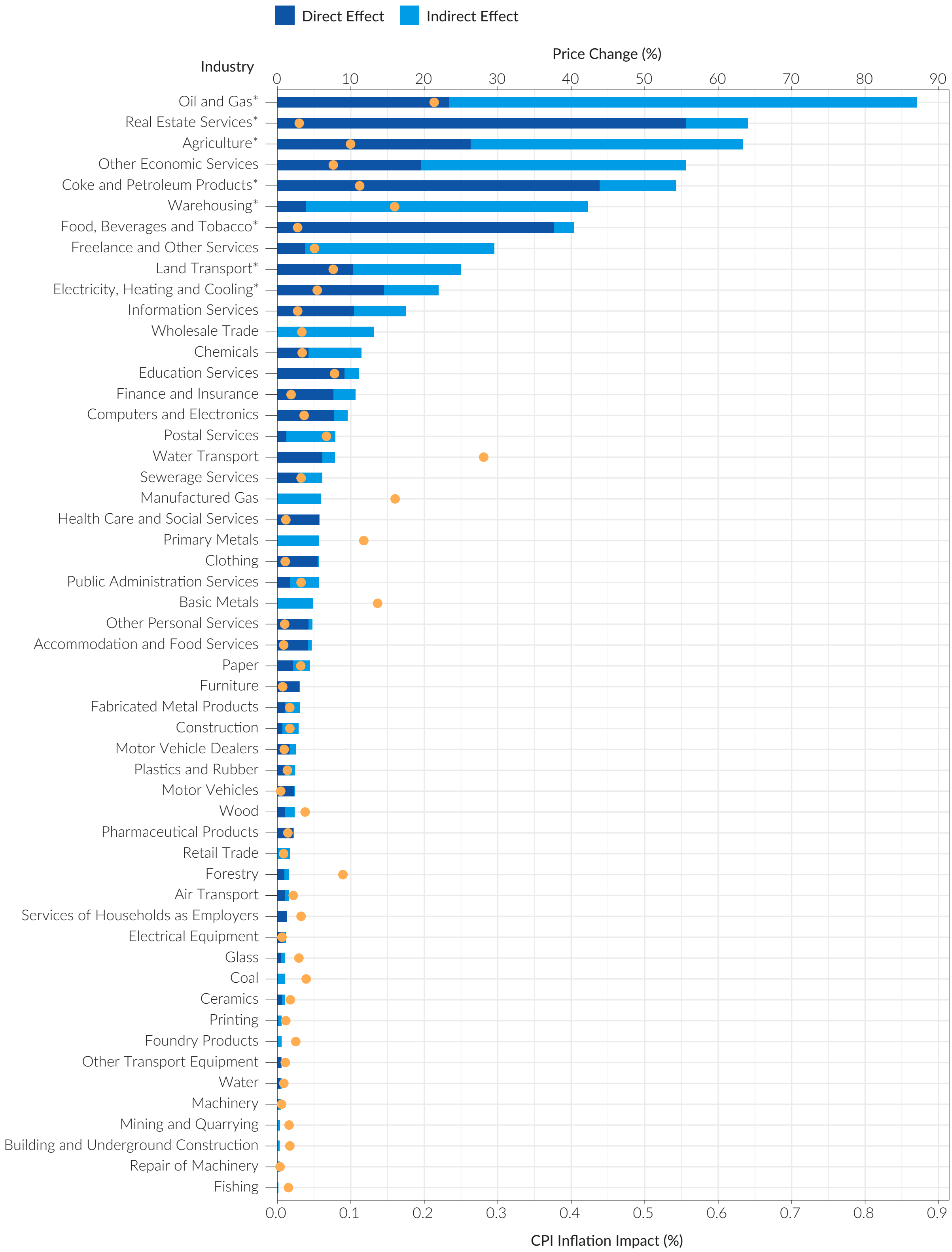
The remaining sectors in the top ten bracket that do not fall into these three groups are Other Economic Services, and Freelance and Other Services. Both are residual categories that rank highly because they bundle together a diverse set of services that are, in combination, relatively upstream, given that nearly all sectors use some services as inputs. However, as residuals they are not very meaningful economic categories. We therefore do not include them in our category of sectors with latent systemic significance.

Even within the top bracket, there are substantial differences in the latent inflation impact. Oil and Gas, with an inflation impact of almost 0.9 percent is by far the most systemically significant sector for inflation. This is because it was the sector with the greatest price volatility and ranks high in the two other dimensions. It is followed by Real Estate Services with an inflation impact of 0.64 percent, trailing Oil and Gas by 0.23 percentage points. On the lower end of the spectrum of sectors

FIGURE 2 CPI inflation impact of average price volatility, 2000-2019



Notes: The graph shows the results of price-shock simulations for all industries using the Leontief price model. The price shock is measured as the average sectoral price volatility between 2000 and 2019 based on the standard deviation of the annual price changes. The combined length of the dark blue (direct effect) and light blue (indirect effect) bars represents the overall impact on CPI generated by a price shock in each sector. The yellow dot represents the magnitude of the price change. Data sources: Destatis Input-Output 2019 tables, Destatis price indices with latent systemic significance, Electricity, Heating and Cooling has an inflation impact of 0.22 percent.

b. Realized systemic significance

To assess the realized systemic significance in the shockflation of the energy crisis, we simulate the inflation impact based on annual price changes in the third quarter of 2022, during the peak of the energy shock (see Figure 3) and before the introduction of the European gas price cap and the German gas price brake (Krebs and Weber, 2024; Weber et al., 2023). Here we find five sectors to have an even more outsized realized inflation impact, compared to the ranking for latent systemic significance. These sectors, in ranking order are: Oil and Gas; Electricity, Heating and Cooling; Food, Beverages and Tobacco; Agriculture; and Coke and Petroleum Products. All five sectors also exhibit latent systemic significance.

Unsurprisingly, given the gas price shock, Oil and Gas has by far the largest inflation impact of 8.4 percent. It's important to note that these inflation figures are not precise estimates since we do not account for substitution in this exercise and the simulation is sensitive to assumptions on passthrough. Nevertheless, the simulated inflation estimate is relatively close to the year-over-year inflation rate in September 2022 (Bundesbank, 2024a), as it includes both direct and indirect effects of the primary inflation driver in the energy crisis. Furthermore, as we demonstrate in the next section, the rankings are generally robust to substitution assumptions. Due to Germany's merit-order-pricing in the power market, electricity prices strongly correlate with gas prices (BMWK, 2022). As a result, we observe a significant price jump for Electricity, Cooling and Heating, close behind that seen in the Oil and Gas and Manufactured Gas sectors.[12] Our analysis, consistent with other studies (e.g., Dao et al, 2023), suggest that energy has been the major driver of the 2022 shockflation. The price increase in Agriculture can also partially be attributed to the rising cost of gas, which is a crucial component in fertilizer production (Adolfsen et al., 2024). In addition, agriculture and food prices have faced an extra shock, due to the market reactions to export blockages on Ukraine (UNCTAD, 2023).

The energy and agrofood price shocks created a perfect storm in which two major points of vulnerability for systemwide price stability were affected.

In our analysis of the next five sectors in the ranking, Chemicals and Manufactured Gas prices surged by 50% and 200%, respectively, as prices in both sectors are also linked to gas prices. The gas price explosion moved them up in the ranking compared to latent systemic significance where they fell into the second bracket. Chemicals, serving as both a critical production input and a final consumption good, exhibited relatively stable prices from 2000 to 2019, which previously excluded the sector from joining the top ten sectors showing latent systemically significant prices. Real Estate Services remain systemically significant. The large increase in Wholesale Trade prices is likely to reflect the price premiums paid in the context of bottlenecks and supply chain issues. Taken together with its high forward linkages, this rendered the sector systemically significant. Both Wholesale Trade and Construction are in the second bracket for latent systemic significance.

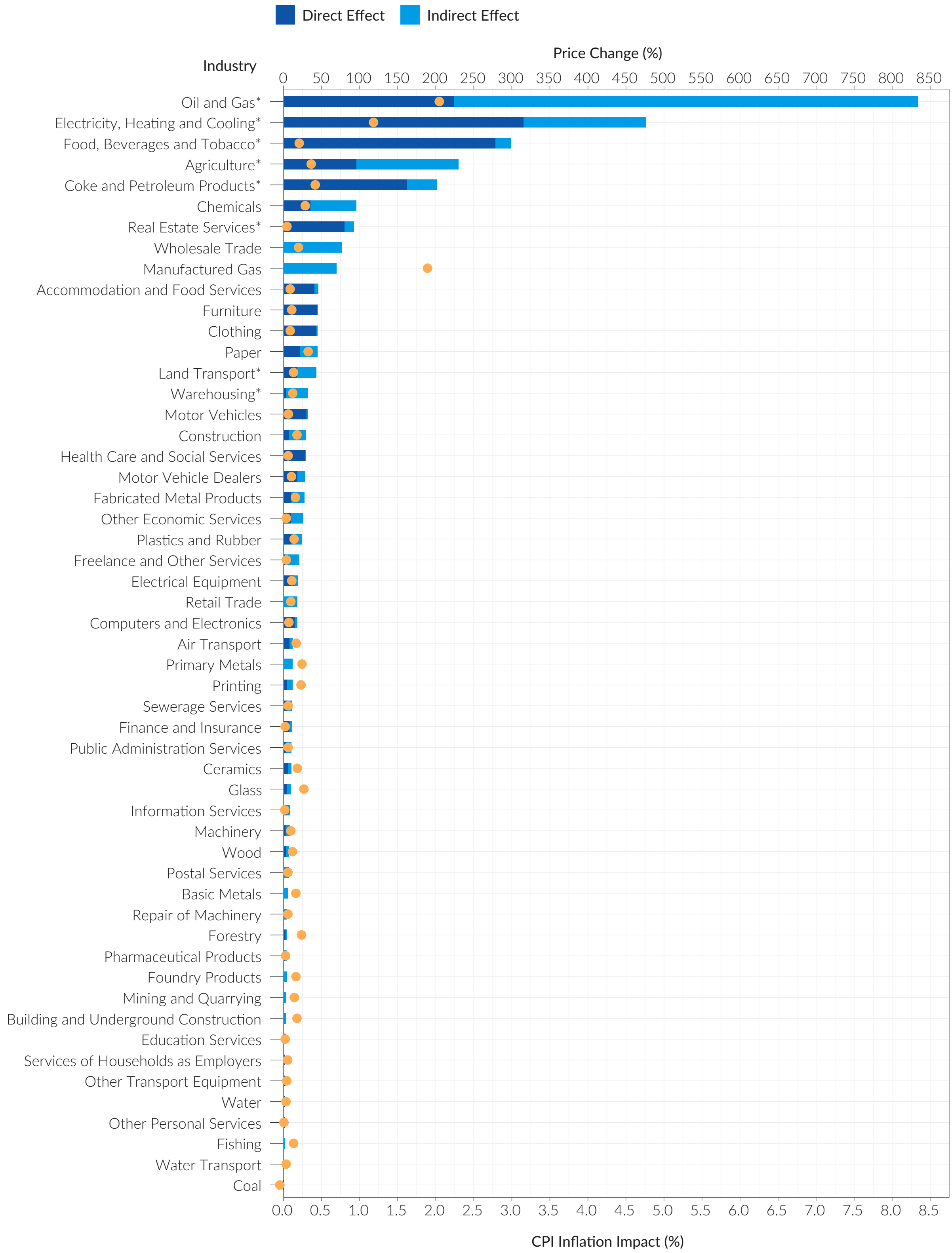
In summary, despite truly extraordinary events, our simulations for pre-COVID price volatilities provide a reliable guide to identifying points of vulnerability. The groups we found to feature latent systemically significant prices also offer useful insights into the dynamics of this historic period of inflation. All sectors from the first group (Essentials for Human Livelihood) and the second group (Energy Inputs) maintained their top-10 status. Finally, within group 3 (Essentials for Commerce), Transportation was demoted to the second bracket, having been surpassed by sectors more directly affected by the gas price shock (i.e., Chemicals, Manufactured Gas) and pandemic-related disruptions (Wholesale Trade).

c. Robustness to varying degrees of passthrough in response to a cost shock

In the simulations presented thus far, we have assumed a full cost passthrough, which implies falling profit shares. However, during the energy price shock, many companies managed to protect their margins and some even increased them in response to the cost shock

12 Note that while TTF market prices for gas surged to 10 times the long-term price trend (Krebs and Weber, 2024), our sectoral price index only increased by 200 percent year-on-year. This discrepancy is partly because gas and oil prices had already risen substantially in 2021, overall oil prices increased much less than gas prices, and our analysis uses quarterly data rather than focusing on the price peak.

FIGURE 3 **CPI inflation impact of yearly price change, Q3 2021 to Q3 2022**



Notes: The graph shows the results of price-shock simulations across all industries using the Leontief price model. The price shock is measured as the annual price change from Q3 2021 to Q3 2022. The combined length of the dark blue (direct effect) and light blue (indirect effect) bars represents the overall impact on CPI caused by a price shock in each sector. The yellow dot represents the magnitude of the price change. Data sources: Destatis Input-Output 2019 tables, Destatis price indices.

(Adolfsen et al., 2024; Arquié and Thie, 2023; Desnos et al., 2023; Dullien et al. 2023; Hahn 2023, Nikiforos et al., 2024; OECD 2023, Weber and Wasner, 2023, Wildauer et al., 2023). According to the IMF, unlike the inflation that followed the oil shocks of the 1970s – when unit labor costs rose more than unit profits – unit profits accounted for a larger share of inflation during the euro area's 2022 energy crisis (Hansen et al., 2023). This suggests that the corporate sector successfully defended, and in some cases enhanced, its profit share.

We therefore alternate our passthrough assumption in model (ii) and simulate a scenario in which firms maintain constant profit shares despite rising costs. This is a minimal version of so-called sellers' inflation, which does not account for margin increases (Weber and Wasner, 2023). Note, however, that maintaining constant margins in response to cost shocks result in an increase in unit profits as a matter of accounting (Hahn, 2023). After an initial impulse stage, driven by shocks to systemically significant prices and followed by a second stage of sellers inflation, where firms protect profit shares, workers may secure wage catch-up after an initial decline in real wages, potentially leading to conflict inflation (Weber and Wasner, 2023). However, this final stage of wage catch-up has yet to take place in Germany, where we have observed the largest real wage decline on record (Krebs and Weber, 2024). To account for the possibility of conflict inflation, we simulate model (iii), where both profit shares remain constant, and wages catch up to restore pre-shock real wages.

Figure 4 presents the rankings for the 2022 shockflation episode using the three different models introduced in the previous paragraph.[13] The top-10 sectors of realized systemic significance remain largely unchanged. The within-group movements are: a decline in Chemicals from six in model i) to nine in model iii), and a rise in Manufactured Gas, from nine in i) to six in iii). The only change in the top 10 happens through the entrance of Retail Trade, from 25 in models i) and ii), to 10 in iii), at the expense of Accommodation and Food Services. The general pattern is that the big changes are found between model iii), conflict inflation, on the one hand, and models i) and ii), on the other. But model iii) is the least relevant to the German case. In other words, the most notable ranking shifts occur when real wages are assumed to remain constant which, empirically, has not been the case in Germany. Intuitively, a shock to a sector's price will have a relatively larger inflation impact in model iii) when it disproportionately affects the prices of goods that are crucial for workers' consumption baskets. This necessitates a substantial wage adjustment to compensate for the initial loss in purchasing power. As shown in Table B.2 in the appendix, conflict inflation leads to a sizable increase in the inflation impact, while leaving the ranking mostly unchanged. In contrast, the inflation impact increase in the moderate sellers' inflation specification is considerably smaller.

d. Robustness to varying degrees of substitution

The ability of firms to substitute gas in the wake of Russia's war of aggression against Ukraine and under the scenario of an immediate gas import embargo has been subject to diverging assessments (e.g., Bachmann et al. 2022; Bundesbank 2022a, b; Krebs 2022). The fierceness of this debate among leading economists and the wide variation of estimates indicates that there is a high degree of uncertainty about the elasticity of substitution, at least in the short run.

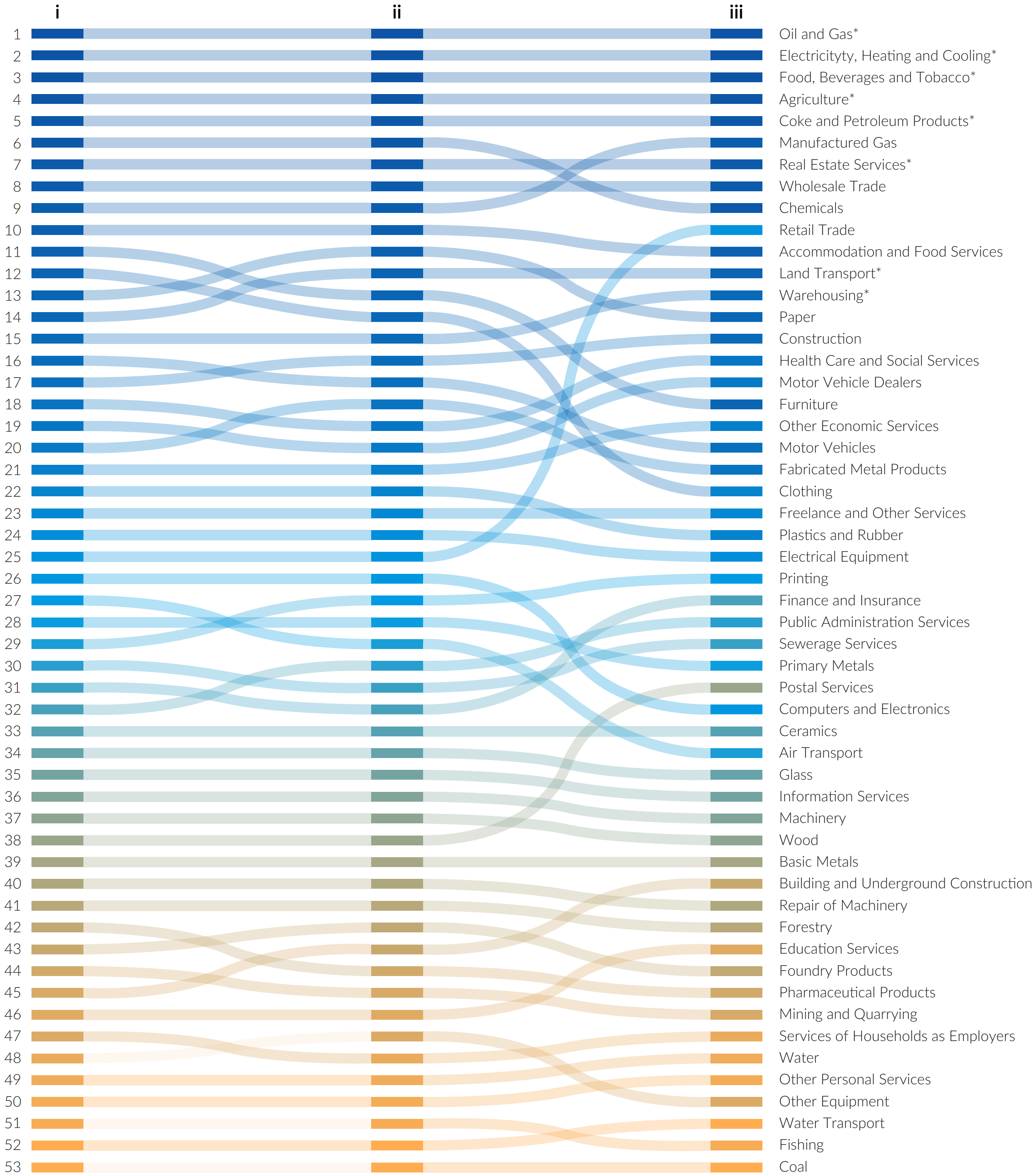
In light of these discussions, our study explores the robustness of identifying realized systemically important sectors by simulating various substitution elasticities. We employ a range of possible substitution elasticities, from a Leontief assumption of complete inelasticity to more optimistic scenarios. Specifically, our simulations include a short-term elasticity of substitution of 0.04 (Bachmann et. al., 2022) and a long-term elasticity of 0.524 (Labandeira et al., 2017), depicted on the left, middle and right sides of the Sankey diagram in Figure 5, respectively. The latter two are pure technological progress substitutions (Bun, 2018).[14]

We assume that the price increase in the industry subjected to the exogenous shock fosters technological progress, which reduces the degree to which other sectors rely on that sector as an input for their production. This technological progress is "pure" in the sense that the reduced reliance does not require an increase in the use of other inputs. We simulate this technological

13 See Table B.2 in the appendix for the exact value of the sectoral inflation impact.

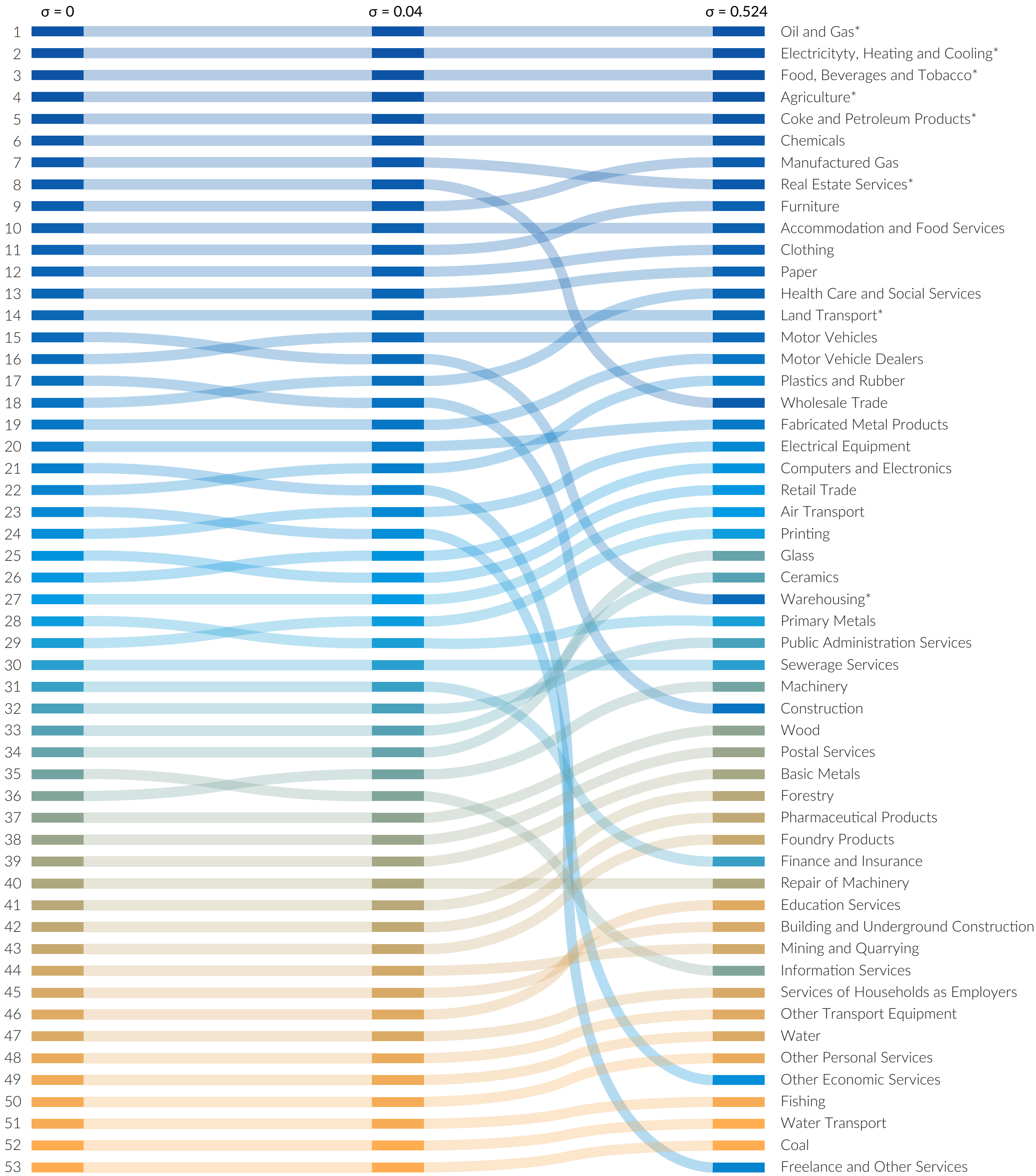
14 It is also possible to simulate various substitution scenarios, such as those involving different energy sources. However, caution is essential when handling changes in input-output technical coefficients. We thus simulate this scenario using elasticities obtained from the empirical literature.

FIGURE 4 **Inflation ranks for simple cost passthrough (i), sellers' inflation (ii) and conflict inflation (iii)**



Notes: The Sankey diagram illustrates the relative impact of industry-specific inflation across various specifications of the Leontief price model, using price changes from Q3 2021 to Q3 2022. The left group of nodes detail the rankings for the baseline model (i), the center group of nodes convey the findings for the profit-adjustment model (ii), and the nodes on the right illustrate those for the wage and profit adjustment model (iii). The connecting lines show shifts in industry rankings between models. This representation synthesizes ranking outcomes across models for the annual price changes. Data sources: Destatis Input-Output 2019 tables, Destatis price indices.

FIGURE 5 **Inflation ranks for different substitution scenarios**



Notes: The Sankey diagram shows the ranking of industry's inflation across different substitution specifications of the price model. The left group of nodes presents the rankings for the Leontief substitution scenario with an elasticity of σ = 0, the center group of nodes shows the rankings of the substitution scenario with an elasticity of σ = 0.04 as considered in Bachmann et al. (2022), and the right side depicts the rankings of the long-run substitution scenario with σ = 0.524 as in Labandeira et al. (2017). The lines indicate the change in rankings for each industry. The Sankey diagram represents ranking results across substitution scenarios for the annual price change from from 2021 Q3 to 2022 Q3. Data sources: Destatis Input-Output 2019 tables, Destatis price indices, elasticities of substitution from Bachmann et al. (2022) and Labandeira et al. (2017).

progress by modifying technical coefficients from the domestic technical requirement matrix. This gives us two different inflation impacts: one obtained without substitution (using the original) and another using the modified. The difference between the two can be interpreted as the reduction in total inflation impact brought about by substitution in the intensity of input use. The sectoral inflation impact across our different substitution scenarios is reported in Table B.2 in the appendix.
Figure 5 illustrates how these varying substitution assumptions affect sectoral rankings. Notably, industries with the largest inflation impact remain mostly stable across scenarios. In other words, even allowing for long-run substitution elasticities does not change these industries' outsized impact on inflation. The only exception is Wholesale Trade, which sees a decline from number eight to 18 in the long-run technical progress scenario. However, rankings of non-systemically significant sectors show greater variability, particularly when comparing short-run and long-run elasticity of substitution. The Oil and Gas sector remains by far the most systemically significant for inflation under any substitution assumption, given our current production structures.

4. "Carbonflation" and systemically significant prices: simulating the inflation impact of sector-level CO_2 price policies

In this section, we illustrate the uncertainty about future carbon prices in Europe and, consequently, the overall magnitude of carbonflation. We identify the most important sectors for carbonflation, that is, inflation induced by increases in carbon prices. These sectors are a subset of the systemically significant sectors for shockflation. Policies targeting systemically significant sectors can thus contain the risk of both carbonflation and shockflation.

a. Uncertain carbon prices

A key instrument in Europe's decarbonization strategy is cap-and-trade, which leads to fluctuating carbon prices (see Figure 6) based on the demand and supply of emissions certificates, both of which are influenced by policy. By 2030, the EU aims to cut emissions by 55 percent from 2005 levels, a significant increase from the previous goal of 40 percent. The target for ETS sectors is a 62 percent reduction, and for sectors in the upcoming ETS2, a 42 percent reduction (European Commission, 2021; UBA, 2023a).[15] The ETS has expanded to cover an increasing number of sectors (see Table B.3 in the appendix for sectoral coverage by the two price systems). Meeting emission targets outside the ETS is the responsibility of individual member states. Germany primarily relies on a parallel national emissions trading system with fixed prices that are scheduled to gradually increase until 2025.[16] In 2026, the price can float between EUR 55/tCO_2 and EUR 65/tCO_2. By 2027, the German national system will merge with the new ETS2, potentially resulting in a significant carbon price increase. Some studies warn that this could reach levels comparable to the price shock during the 2022-2023 energy crisis, accounting for the price-dampening effects of energy price brakes for final users (Bayer and Bachmann, 2023; Dullien et al., 2024; Kalkuhl et al., 2023). As noted by Brigitte Knopf, an expert in German climate policy, "it is uncharted territory… we really don't know where we will end up with the prices" (Wettengel, 2023).

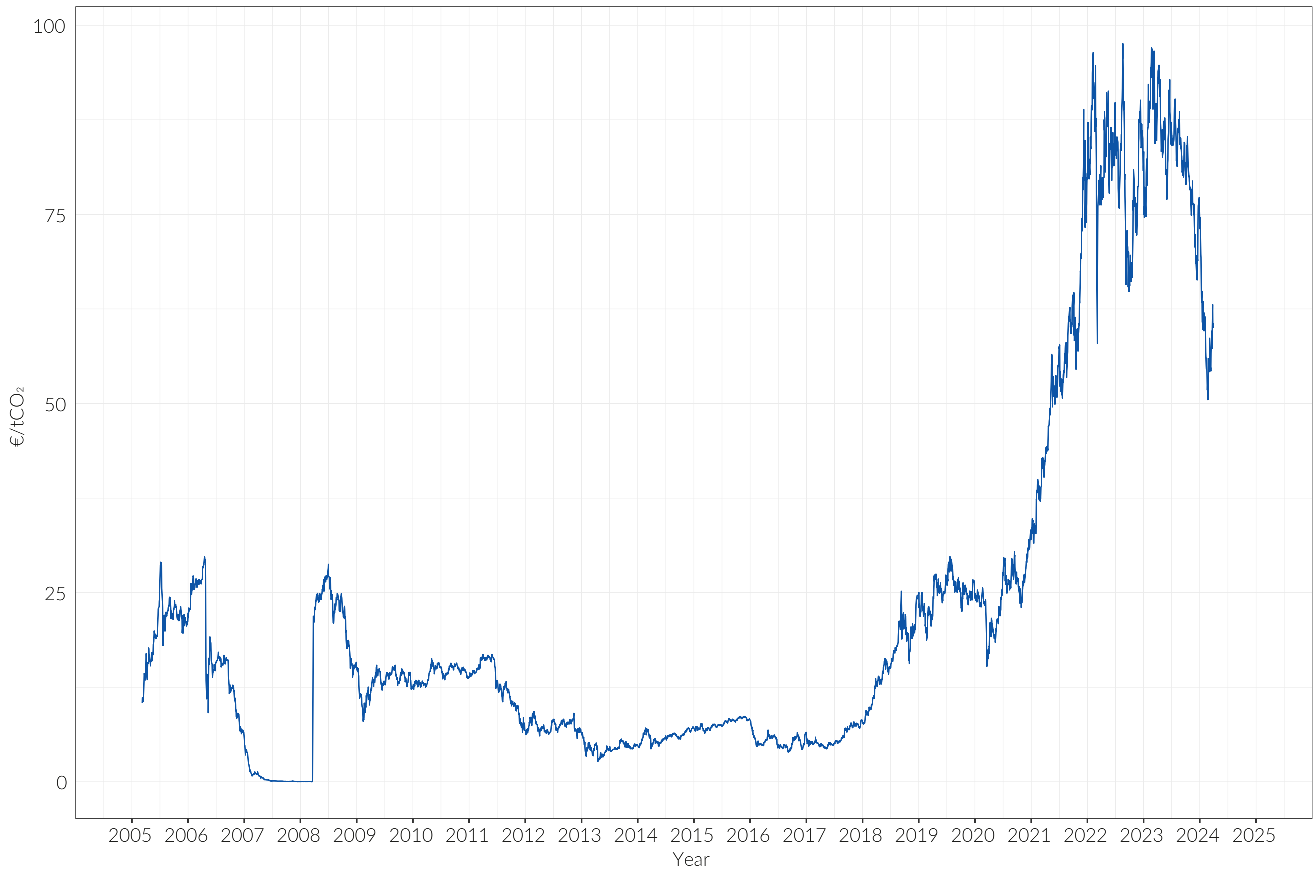
For example, Pietzcker et al. (2021) use the REMIND-EU Integrated Assessment Model to estimate carbon price levels that align with the EU's 2030 targets, assuming emission pricing is the only new climate policy.[17] Their estimates range significantly based on assumptions about market ramp-up speed, technology adaptation, and the international environment. Carbon prices are projected for the year 2030 and may either gradually increase or experience sudden jumps. The estimates

15 The ETS2, which will become fully operational in 2027, is designed to help EU member states achieve their emission reduction targets as defined under the Effort Sharing Regulation (ESR). Most ESR sectors will be covered by the ETS2, with the notable exception of the agricultural sector.

16 Germany initially pursued climate change mitigation with its Energiewende agenda, which pioneered a mission-oriented approach relying on feed-in tariffs that guaranteed renewable energy producers a fixed price for every kilowatt hour generated (Hake et al, 2015; Mazzucato, 2018). But in 2016, Germany switched to a more market-based paradigm centered on auctioning (Leiren and Reimer, 2018).

17 REMIND-EU is an expansion of the REMIND 2.1 model, a multiregional integrated assessment model that provides a detailed representation of the energy sector within the context of long-term macroeconomic developments (Baumstark, 2021). The model is continuously updated, incorporating policy tools such as non-pricing policies, which can reduce the necessary carbon prices. In this study, however, Pietzcker et al. (2021) focus solely on carbon prices as the only tool for climate mitigation measures.

FIGURE 6 **EU ETS price**



Notes: The graph shows the allowance price in the ETS1 for one ton of CO_2 from 2005 to 2024. Source: ICAP Allowance Price Explorer.

vary by approximately 100 percent depending on scenario assumptions: For the ETS1, CO_2 price estimates range between EUR 95/tCO_2 and EUR 210/tCO_2, and for the ETS2, between EUR 210/tCO_2 and EUR 405/tCO_2. Note that the ETS1 price averaged EUR 83.5/tCO_2 in 2023. The most significant factor affecting their CO_2 price estimates is the pace of market ramp-up. A faster and smoother market ramp-up for new technologies like electric vehicles and renewable energy results in lower CO_2 prices needed to achieve emissions reduction targets. Conversely, factors that impede a fast market ramp-up, such as high interest rates, can lead to higher carbon prices for the same emissions reduction target.

For our carbonflation simulation, we use Pietzcker et al.'s (2021) carbon price estimates for 2030. Overall, the pessimistic scenario aligns best with the actual carbon prices in 2022 and 2023 when using a linear extrapolation of prices from 2021 to 2030, following a recent IMF study (Konradt et al., 2024). However, even this pessimistic scenario would have underestimated the actual prices in 2022 by EUR 8.6/tCO_2 but overestimated those in 2023 by EUR 5.96/tCO_2. For the ETS2 sectors, we use the existing fixed prices of the national carbon price system in Germany until 2026. For the start of ETS2 in 2027, we follow Kalkuhl et al. (2023) and assume a price jump. Figure 7a) plots these price paths.

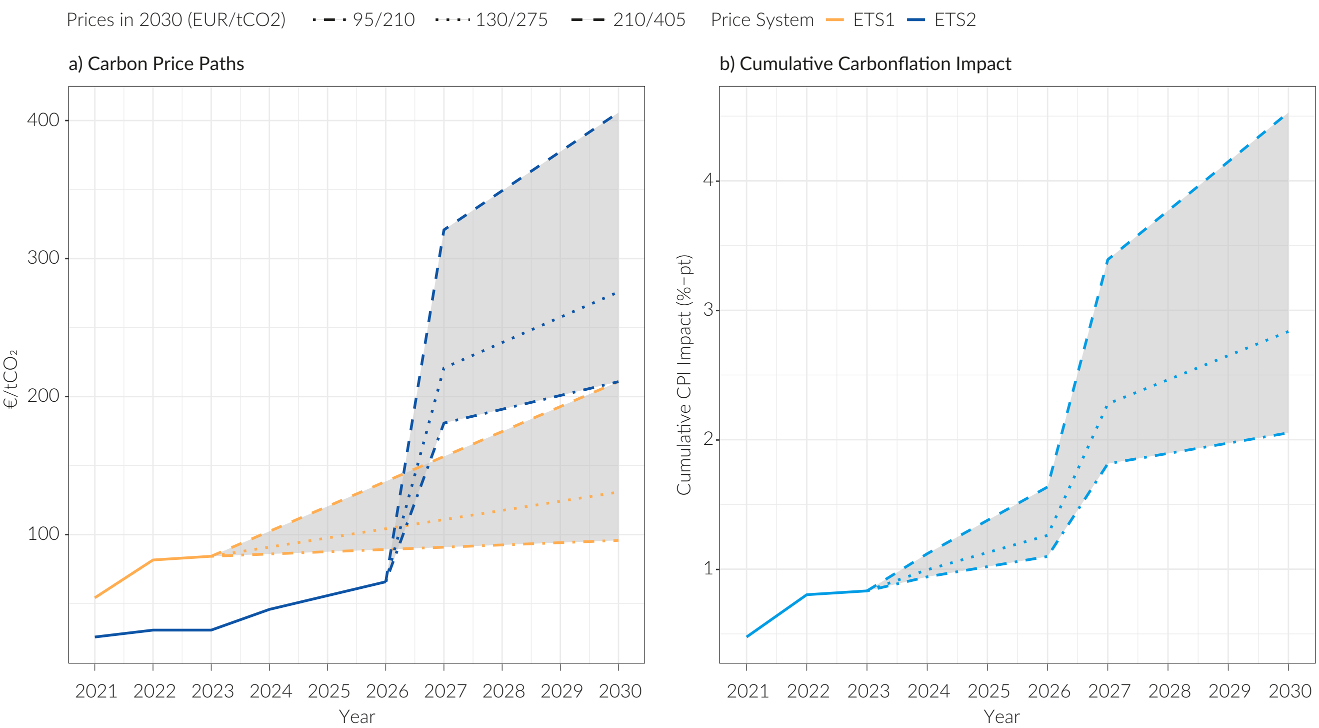
b. Carbonflation risk

If market participants can pass on carbon prices, a carbon price policy can generate inflation (Delgado-Téllez et al., 2022; Konradt et al., 2024; Nöh et al., 2020; UNEP and NIESR, 2022). However, the degree of carbonflation is even more difficult to pin down than future carbon prices. In addition to uncertainty around carbon price increases, there is uncertainty around passthrough and substitution effects. Furthermore, cumulative carbonflation can vary widely depending on carbon price volatility, particularly if the passthrough of carbon prices changes is asymmetric for increases and declines. This is the well-known rockets-and-feathers phenomenon: prices go up with costs like rockets but fall like feathers. To capture the full range of possible carbonflation over time, a dynamic modeling approach is required. For simplicity, we focus here on the variation in carbonflation from different carbon prices (see Figure 7a), which already leads to a wide range of outcomes.

For passthrough, we assume that firms keep their margins constant in response to increased costs of emissions (see section 3.c).[18] We do not include any wage adjustments to protect real wages, considering the potential implementation of a climate cash transfer ("Klimageld"). We keep the weighting of different sectors in the CPI constant and attribute household emissions to the sectors Real Estate Services and Land Transport based on Agora Energiewende and Agora Verkehrswende (2023). Otherwise, these sectors would not be part of our model, leading to a substantial underestimation of carbonflation. Note that we do not simulate carbon pricing under the Carbon Border Adjustment Mechanism (CBAM), which takes effect in 2026; thus, unlike our shockflation simulations, the prices of imports remain unchanged.

Our simulations are further based on the assumption that carbon price policy works as intended,[19] that is, carbon prices stimulate substitution away from the use of emission-intensive goods and services. Following Konradt et al. (2024), we assume substitution through technological progress using the same elasticities.[20] In response to the carbon price signal, companies in all sectors are assumed to switch to more efficient technologies that produce the same output with less emission-intensive inputs.

FIGURE 7 Carbon price paths and cumulative carbonflation impact



Notes: Panel a) shows carbon price paths from 2021 to 2030. From 2021 to 2023, ETS1 prices are the actual averaged yearly prices calculated by the authors based on ICAP (2024). Prices for the ETS2 sectors follow the fixed prices of the German national carbon price system until 2026. Target carbon prices in 2030 are based on Pietzcker et al. (2021). The lower bound carbon prices are EUR 95/t€/tCO_2 for the ETS1 sectors and EUR 210/t€/tCO_2 for the ETS2 sectors; the moderate carbon prices are EUR 130/t€/tCO_2 and EUR 275/t€/tCO_2; and the upper bound carbon prices are EUR 210/t€/tCO_2 and EUR 405 /t€/tCO_2, respectively. Panel b) shows the simulated cumulative total inflation impact that corresponds to the price paths in panel a). Data sources: Destatis Input-Output 2019 table, carbon prices from Pietzcker et al. (2021), ETS prices from ICAP (2024).

18 The exception applies to firms in sectors that reported a negative operating surplus. These sectors are represented in the same way as in the benchmark model.

19 This might not be the case, for example, if firms pass on the price increases instead of updating their technology (Desnos et al., 2023).

20 The elasticities of substitution are -0.24 percentage points for coal, -0.17 percentage points for electricity, -0.27 percentage points for natural gas and -0.001 percentage points for crude oil and refined petroleum.

The main result from our carbonflation simulation, as displayed in Figure 7b, is that there is major uncertainty around the inflationary impact of carbon pricing, evident from the large variation in required carbon price levels alone. The cumulative inflation impact across our three scenarios ranges from 2 percentage points in the most optimistic scenario (lower bound CO_2 prices) to 4.5 percentage points in the more pessimistic scenario (upper bound CO_2 prices). This translates into an average annual carbonflation that increases inflation by 0.2 percentage points to 0.45 percentage points. Therefore, carbonflation could range from 10 percent to nearly a quarter of the annual ECB inflation target of 2 percent. From 2026 to 2027, a jump in inflation occurs due to the assumed price shock with the transition to ETS2 (see Figure 7b). In that year, the simulated carbonflation ranges from 0.7 percentage points to 1.8 percentage points, meaning carbonflation alone would account for 35 percent to 85 percent of the ECB inflation target. In reality, carbon prices formed in an emissions trading system are volatile, implying that the annual carbonflation estimates based on smooth price paths presented here might well underestimate actual carbonflation.

Our carbonflation estimates are consistent with the literature, accounting for modeling choices. For a slightly shorter period and with a price increase of EUR 112/tCO_2, Konradt et al. (2024) find a cumulative CPI impact for the euro area between 1.8 percentage points and 3.7 percentage points using an input-output approach, with variation depending on assumptions about pass-through. Another estimate for annual carbonflation in the euro area based on 2030 carbon prices of EUR 120/tCO_2 and EUR 200/tCO_2 is 0.15 percentage points and 0.4 percentage points, respectively (Delgado-Téllez et al., 2022). Nöh et al. (2020) project a larger cumulative CPI impact for the national carbon price in Germany. Using a German income and consumption survey, they examine price changes within households' consumption baskets and find an average annual CPI increase of 0.43 percentage points.[21] In comparison, our largest simulated annual carbonflation impact is 0.26 percentage points in the same period that includes both emission trading systems. However, the authors stress the possibility of double-counting indirect effects, potentially overlapping with ETS emissions in their analysis. Additionally, unlike our analysis, Nöh et al. (2020) do not account for substitution effects, which may explain the relatively large difference between the CPI impacts.

c. Systemically significant prices for carbonflation

The literature on carbonflation has primarily focused on the overall inflation impact of carbon price policies. Our modeling approach allows us to identify which sectors are most significant for carbonflation. There is a wide spectrum of possible climate mitigation policies, ranging from relying exclusively on carbon pricing (as assumed in the previous section's simulation of cumulative carbonflation) to non-price-based policies such as investment programs, regulations, standards, behavioral norms, or a policy mix combining carbon pricing and non-price measures (Grubb et al., 2023). Targeting non-price-based policies at sectors with the greatest potential contribution to carbonflation can help navigate the uncertain inflationary effects of carbon pricing. Preventing carbonflation should be one of the considerations in determining the policy mix.

To identify systemically significant prices for carbonflation, we proceed similarly to our shockflation analysis. We calculate the carbonflation impact of a CO_2 price applied to one industry at a time and rank sectors according to this impact. Adding up all the sectoral carbonflation impacts is equivalent to simulating the effect of a CO_2 price for all industries simultaneously. Therefore, unlike for shockflation, we can also determine the share that any one sector contributes to total carbonflation.

We first simulate a potential carbon price shock in 2027, which presents the most immediate risk of carbonflation. A linear projection from the actual ETS1 price in 2023 to Pietzcker et al.'s (2021) price estimates for 2030 results in an almost flat curve for the lower bound prices, which is not plausible given the European emission reduction targets meant to be achieved by carbon prices alone. To simulate two plausible magnitudes of shocks, we take the middle and upper bound carbon price increases for the ETS2 sectors from 2026 to 2027 as depicted in Figure 7a: EUR 155/tCO_2 and EUR 255/tCO_2, respectively. For ETS1 sectors, we take the projected middle and upper price bound for 2026 and assume that the price increase to 2027 aligns with the annual price volatility from 2020 to 2023 when the current ETS1 configuration has been in operation. This gives us carbon price changes of EUR 13/tCO_2 and EUR 17/tCO_2.

21 Own calculation based on the author's total inflation impact of 2.6 percentage points during a period of six years between 2021 and 2026.

Figures 8a and 8c show our sectoral carbonflation rankings for the two magnitudes of carbon price shocks. The length of the bar represents the change in the CPI for the respective industry. The dot represents the magnitude of the change in sectoral prices caused by a carbon price change. As before, the direct effect captures the change in the CPI due to the price change in the industry that pays the increased CO_2 price, and the indirect impact captures the price changes that follow in all other industries. Note that the relatively small indirect effects compared to shockflation are due to simulating only the EU internal carbon price changes, while some key upstream inputs such as oil and gas are largely imported.

We find that in the simulation of carbon price shocks, five sectors have an outsized impact on carbonflation: Land Transport, Real Estate Services, Electricity, Heating and Cooling, Coke and Petroleum Products, and Food and Tobacco Products.[22] Land Transport and Real Estate Services are also sectors that will enter ETS2 in 2027, explaining their top ranks in this simulation. Jointly, these five sectors account for 74 percent and 73.8 percent of the total carbonflation increase of 1.07 and 1.7 percentage points, respectively. If we consider the larger carbon price shock, the Land Transport sector alone induces an inflation increase of 0.54 percentage points, more than a quarter of the annual inflation target.[23]

The price jump in 2027 affects ETS2 sectors more than ETS1 sectors. To assess which sectors are systemically significant for carbonflation in the medium run, we use the increase from the 2023 carbon price levels to the projected 2030 prices for the next simulation (Figure 9). We find that the same five sectors as in the simulation of the 2027 carbon price shock, plus Oil and Gas, exert the largest carbonflation impact. Jointly, these six sectors account for 76.9 percent and 78.1 percent of the total carbonflation of 1.97 and 3.61 percentage points, respectively. All six sectors are also systemically significant for shockflation (see Table 1). These six sectors should be a prime focus for policymakers aiming to contain inflation risks.[24]

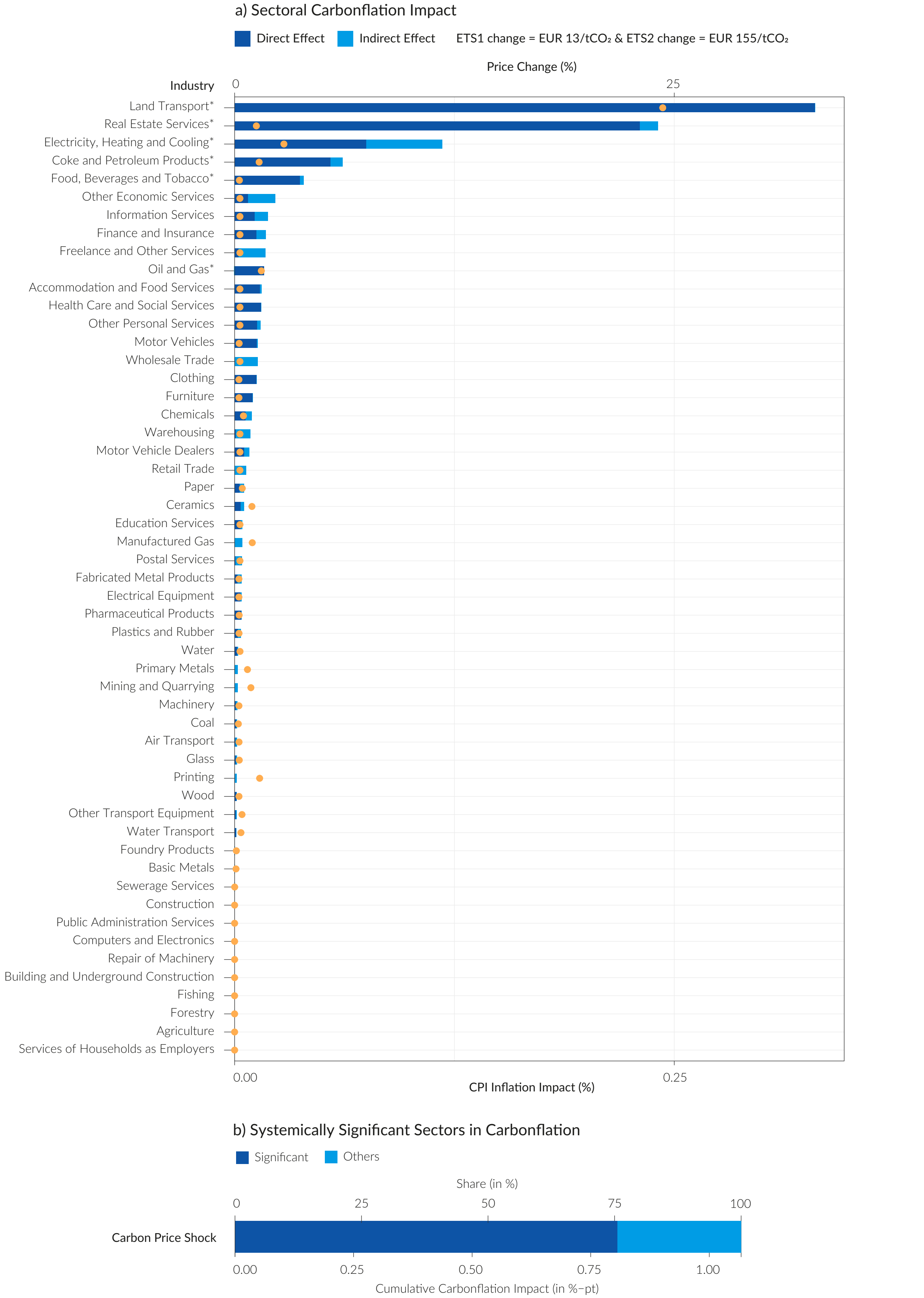
The overlap of systemically significant prices for carbonflation and shockflation can be explained by the strong relation between emission intensity and price volatility. Figure 10 illustrates this relationship. Fossil fuel prices are among the most volatile prices, and fossil fuel intensity is also correlated with emission intensity. As we have seen, systemic significance for shockflation is determined via three channels: weight in CPI, forward linkages, and the magnitude of the price shock. For carbonflation, the latter channel is replaced by the magnitude of the carbon price increase, which reflects the sectoral emission intensity. Electricity, Heating and Cooling; Coke and Petroleum Products; and Oil and Gas are important for carbonflation due to their emissions intensity, centrality as production inputs (ranks 12 to 14 of all sectors in terms of forward linkages), and relatively high weights in the CPI. In contrast, the Real Estate Services sector ranks high due to its importance as a production input (rank 11 in terms of forward linkages) and its high weight in consumer baskets, meaning that even smaller policy-induced price changes have a large impact on the CPI. Land Transport ranks high due to its high emission intensity and centrality as a production input (rank 10 in terms of forward linkages).

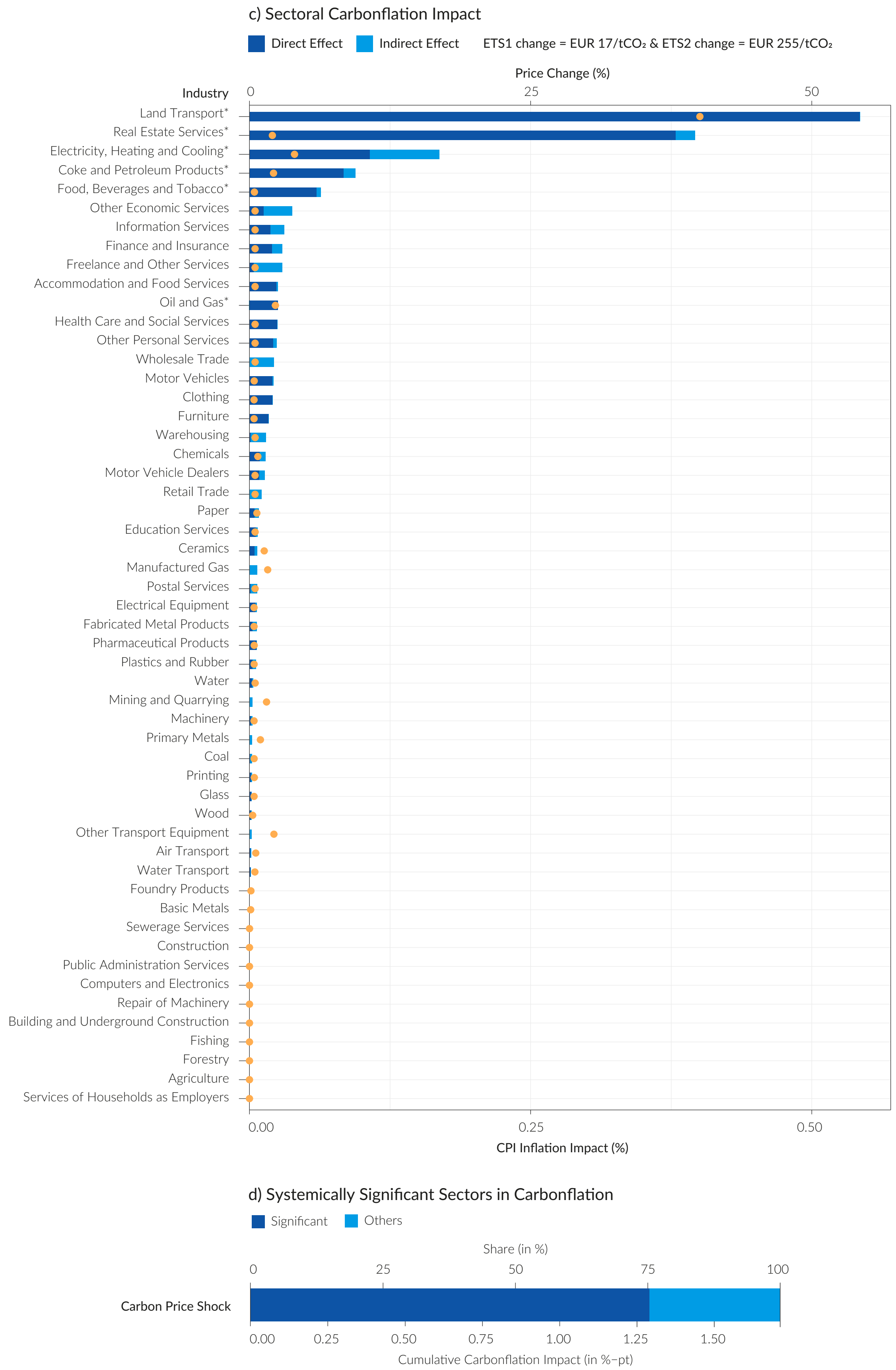
22 As discussed, the Real Estate Services as well as Land Transport sectors include household emissions, thus intensifying the overall inflation impact of these sectors.

23 Some energy intensive industries like primary metals or foundry products are relatively low in the ranking since they have a low weight in the CPI, and the indirect effect of these sectors is small because large shares of their outputs are inputs into their own sector.

24 It is important to note that carbon pricing generates tax revenue for governments, sparking debate on how to utilize these revenues. Some options, such as financing infrastructure, subsidizing green technologies, and cutting taxes, could reduce inflation. Other possible policies address the consequence of inflation, such as lump-sum transfers to low-income households (Wills et al. 2022). Since we are not discussing these alternative recycling schemes and their outcomes, we present the maximum inflationary impact here as a cautionary example of the worst-case scenario.

FIGURE 8 **Sectoral carbonflation impact and share of systemically significant sectors with carbon price shock from 2026 to 2027**

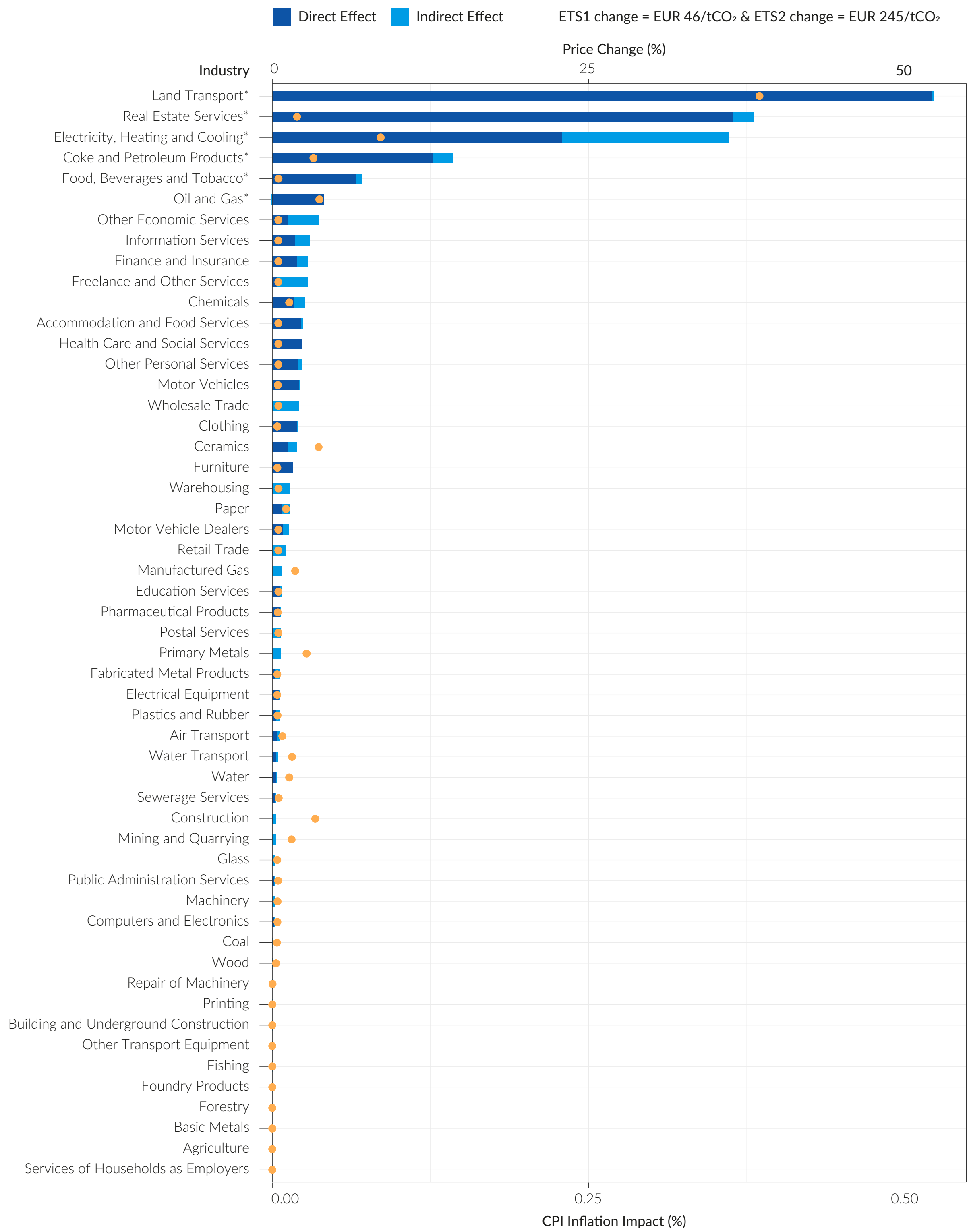




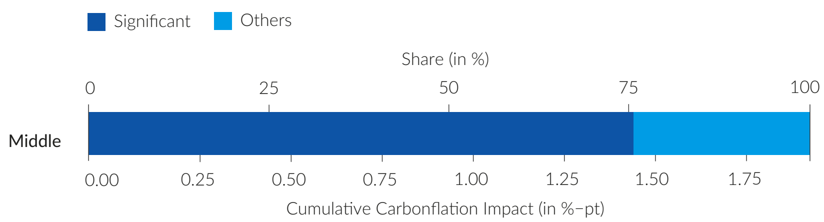
Notes: The graph shows the results of our two carbon price shock scenarios using the Leontief price model. Panels a) and b) show the outcome for an ETS1 shock of EUR 13/tCO₂ and an ETS2 shock of EUR 155/tCO₂. Panels c) and d) depict the outcome for an ETS1 shock of EUR 17/tCO₂ and an ETS2 shock of EUR 255/tCO₂. Panels a) and c) show the results for all industries. The combined length of the dark blue (direct effect) and light blue (indirect effect) bars represents the overall impact on CPI generated by a carbon price shock to the respective sector. The yellow dot shows the magnitude of the sectoral price change due to the carbon price shock. The bar plots in panels c) and d) show the total inflation impact of the respective carbon price shock and the share of the systemically significant sectors therein (blue bar).

FIGURE 9 Sectoral carbonflation impact and share of systemically significant sectors, 2023-2030

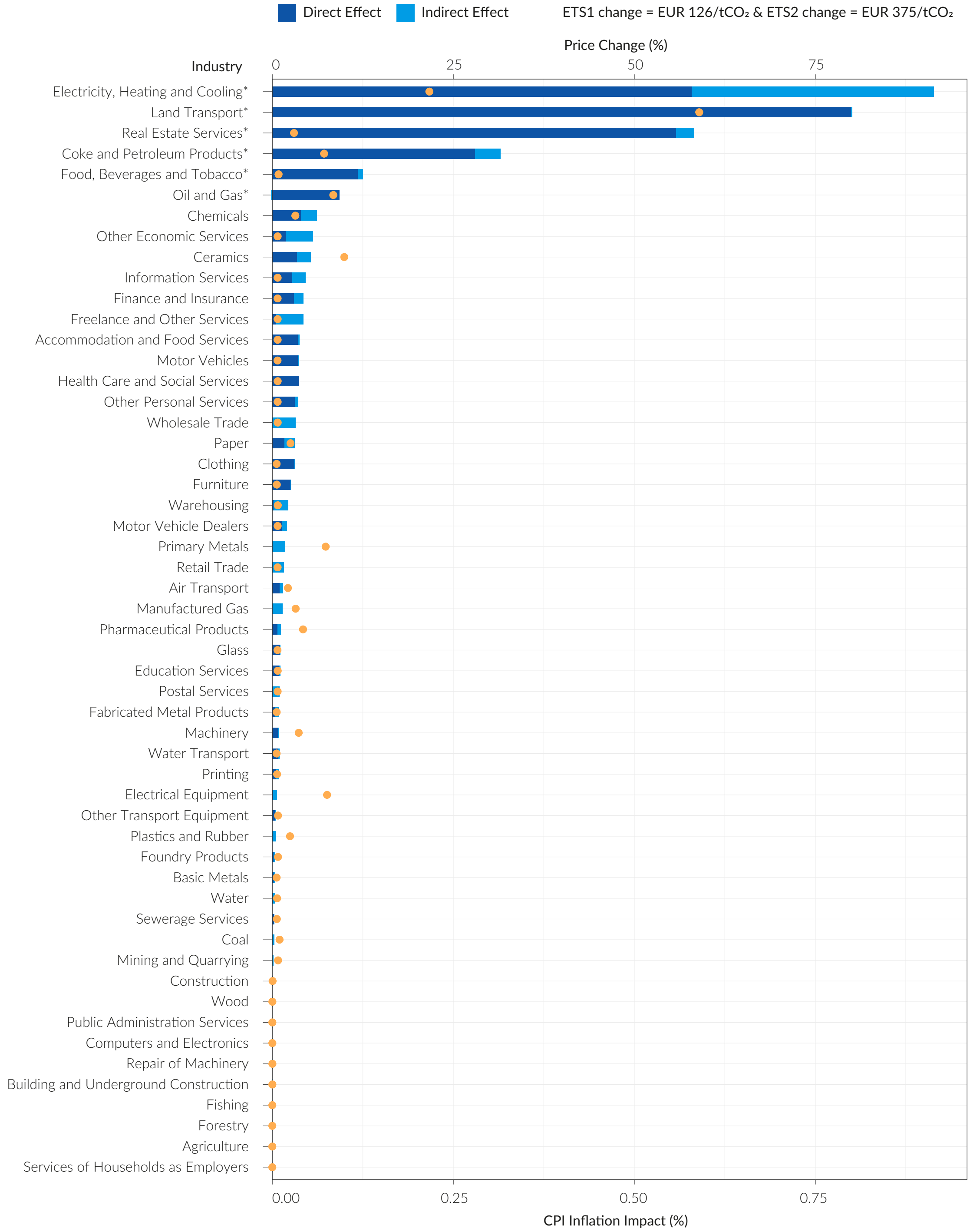
a) Sectoral Carbonflation Impact



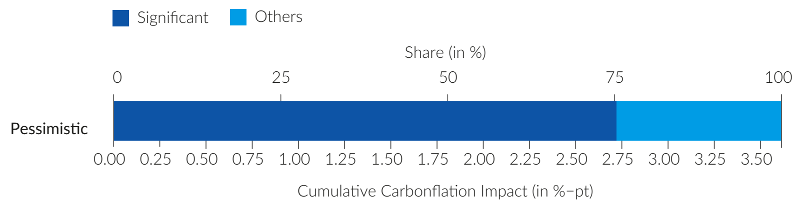
b) Systemically Significant Sectors in Carbonflation



c) Sectoral Carbonflation Impact

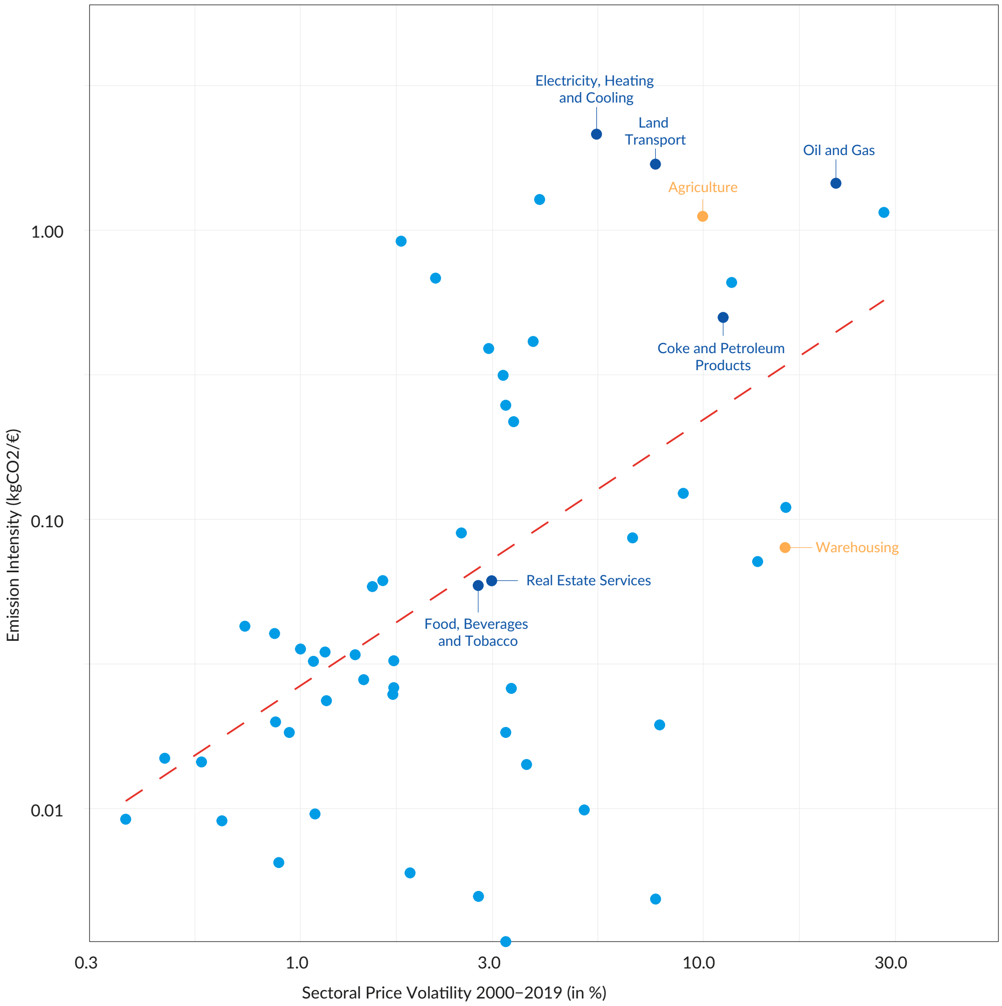


d) Systemically Significant Sectors in Carbonflation



Notes: The graph shows the inflation impact of linear carbon price increases between 2023 and 2030 using the Leontief price model. Panels a) and b) show the impact for the ETS1 price increase of EUR 46/tCO₂ and the ETS2 price increase of EUR 245/tCO₂. Panels c) and d) depict the outcome for the ETS1 price increase of EUR 126/tCO₂ and the ETS2 price increase of EUR 375/tCO₂. Panels a) and c) show the results for all industries. The combined length of the dark blue (direct effect) and light blue (indirect effect) bars represents the overall impact on the CPI generated by the carbon price increase for the respective sector. The yellow dot shows the magnitude of the sectoral price change due to the carbon price increase. The bar plots in panels c) and d) show the total inflation impact of the respective carbon price increase and the share of the systemically significant sectors therein (blue bar).

FIGURE 10 Emission intensity vs. sectoral price volatility



Notes: The figure displays the correlation between emission intensity ($kgCO_2$/€) and sectoral price volatility (in percent). The dark blue points are sectors that are systemically significant for both shockflation and carbonflation. The yellow dots are systemically significant for shockflation only. The turquoise points are all other sectors. The figure is in log-log scale. Source: Destatis environmental economic accounting, own calculation, Destatis price indices.

5. Policy conclusions

Our analysis yields two main findings. First, future carbon prices, and hence the magnitude of carbonflation, are highly uncertain but could potentially reach levels that challenge monetary stability – even without accounting for the CBAM. Simulated annual carbonflation ranges from 0.2 percentage points with moderate, linear price increases to 1.7 percentage points for a potential carbon price shock in 2027. Second, six sectors are systemically significant for both shockflation and carbonflation (Table 1). Together, these six sectors – Electricity, Heating and Cooling; Coke and Petroleum Products; Oil and Gas; Real Estate Services; Food and Tobacco Products; and Land Transport – account for 77 to 78 percent of total carbonflation. Additional sectors significant for shockflation but not carbonflation include Agriculture and Warehousing. Agriculture, not part of the ETS, is excluded from our carbonflation simulation despite being a major carbon dioxide emitter (see Figure 10). Simply put, the key to preventing both shockflation and carbonflation lies in the energy, housing, food, and transportation and logistics sectors.

Today's macroeconomic stabilization regime relies on interest rate hikes and fiscal tightening in response to inflation, effectively pushing down the entire economy in response to sectoral price increases. A new policy toolbox is needed to address inflation in a world of shocks and under the imperative of climate change mitigation in a more targeted manner (van 't Klooster and Weber, 2024). The new approach should focus on preventing and containing price spikes in sectors crucial for system-wide price stability. Just as the 2008 global financial crisis led to recognizing that some financial institutions are too big to fail, it is time to acknowledge that some sectors are too-essential-to-fail. Systemically significant sectors require monitoring, stress testing, and regulation (van't Klooster and Weber, 2024). The state must also be prepared to intervene when necessary.

Policymakers must combine stabilization with transformation efforts for systemically significant sectors. One key instrument in achieving these goals is public buffer stocks (Weber and Schulken, 2024). These can be both physical (buying, storing, and selling actual commodities) and virtual (counter-cyclical open market operations in commodity futures markets) (von Braun and Torero, 2009; Hockett and Omarova, 2016). Buffer stocks can keep critical prices within a certain range and serve as an industrial policy tool by guaranteeing markets and setting incentives through public procurement.

Both too low fossil fuel prices and fossil fuel price spikes present a challenge for green transition efforts. Price explosions like those witnessed during the 2022 energy crisis result in profit explosions which exacerbates the challenge of relatively low profitability in renewables (Christophers 2024; Weber, 2022). This can also cause inflation which, under the current macroeconomic stabilization regime, leads to interest rate hikes that adversely affect green investments (Dao et al., 2024; van't Klooster and Weber, 2024).

The EU could set price corridors for fossil fuel prices in the European market. Carbon prices could be countercyclical using the Market Stability Reserve to prevent simultaneous oil and gas price spikes and ensure a price floor (Bofinger, 2021; Blanz et al., 2022). A European Strategic Energy Reserve (ESER), modeled on the U.S. Strategic Petroleum Reserve (SPR) but including renewables could be established. Together with a mechanism such as the European gas price cap that leverages Europe's power as a buyer in international markets, an ESER could release energy supplies in response to price spikes and thus help enforce a price ceiling.

Unlike the SPR, the ESER could be built on a mix of energy sources and thus facilitate both stabilization and decarbonization. It could be designed to buffer Europe against fossil fuel price shocks while accelerating the development of renewables. Renewable energy pools, guaranteeing purchase prices to producers and consumers as proposed by Neuhoff et al. (2024), could be part of such a strategic reserve. Stabilizing the costs of renewables also requires stabilizing prices of critical upstream inputs, like minerals, a concept introduced by Mario Draghi (2024). Buffer stocks could ensure market stability, encourage investments, and prevent bottlenecks in these inputs. They could also stabilize agricultural producers' incomes, prevent food price spikes, and promote climate-resilient crops and low-carbon fertilizers (Weber and Schulken, 2024).

A second key pillar in achieving stabilization and transformation is green industrial policy. Its potential to contain carbonflation while reducing the vulnerability to shockflation should be added to the advantages economists attribute to industrial policy (Chang and Andreoni, 2020; Rodrik, 2015). Massive investments are needed to build renewable energy systems, decarbonize transportation, retrofit housing, and green the food system. States can successfully induce sectoral technological change (Meckling and Nahm, 2018). This is not merely a market failure issue to be corrected with a carbon price but requires market creation and shaping, necessitating public investment (Mazzucato and Semieniuk, 2017). Conditionalities, regulation, and standard-setting for systemically significant sectors are essential tools to complement public investments (Mazzucato and Rodrik, 2023).

In Germany, a recent study suggests that EUR 554.3 billion in public investments are needed to enhance housing, transport infrastructure, decarbonization, and climate adaptation (Dullien et al., 2024). These investments would strengthen the resilience of systemically significant sectors, reducing the risk of shockflation, lowering emissions, and helping achieve EU targets. At the same time, a swift market ramp-up for green technologies and infrastructure enabled by public investments would limit the increase in carbon prices and thus contain the risk of carbonflation. Current fiscal rules, based on outdated stabilization paradigms, prevent necessary public investments. Instead of serving greater macroeconomic stability, they end up increasing the vulnerability to future inflation shocks by constraining states' ability to effectively mitigate climate change. This underscores the need for states to develop a new stabilization toolbox that allows them to facilitate a green transformation and navigate a world of shocks.

Table 1: Systemically significant sectors for shockflation and carbonflation

Sector	SSS for Shockflation (inflation impact)	SSS for Carbonflation (inflation impact)	Weight in CPI	Forward linkages (rank)	Price volatility (rank)	Emission intensity (rank)
Electricity, Heating and Cooling	latent (0.2%) realized (4.8%)	Cumulative 2030 (0.36% - 0.9%) 2027 carbon price shock (0.12% - 0.17%)	0.027	12	14	1
Oil and Gas	latent (0.8%), realized (8.3%)	Cumulative 2030 (0.04% - 0.09%) 2027 carbon price shock (0.016% - 0.025%)	0.011	13	2	3
Coke and Petroleum Products	latent (0.5%), realized (2%)	Cumulative 2030 (0.14% - 0.3%) 2027 carbon price shock (0.06% - 0.09%)	0.039	14	7	10
Real Estate Services	latent (0.6%), realized (0.9%)	Cumulative 2030 (0.38% - 0.6%) 2027 carbon price shock (0.24% - 0.4%)	0.186	11	25	23
Food, Beverages and Tobacco	latent (0.4%), realized (3%)	Cumulative 2030 (0.07% - 0.12%) 2027 carbon price shock (0.04% - 0.06%)	0.136	31	28	24
Land Transport	latent (0.3%), realized (0.43%)	Cumulative 2030 (0.52% - 0.8%) 2027 carbon price shock (0.33% - 0.54%)	0.014	10	12	2
Agriculture	latent (0.6%), realized (2.3%)	No	0.026	30	8	6
Warehousing	latent (0.4%), realized (0.3%)	No	0.002	4	4	20

Notes: The table shows the results for our systemically significant sectors. Columns 2 and 3 show the sectors' impact on shockflation (latent and realized) and carbonflation (both cumulative and carbon price shocks). Column 4 provides the CPI weight of the sectors, calculatedbased on each sector's weight in the consumption interdependence table ("Konsumverflechtungstabelle") and the corresponding weight of each category in the CPI. Columns 5 to 7 display the sectors' ranks in for ward linkages, price volatility between 2000 and 2019, and emission intensity. Authors' own calculation.

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Appendix

Appendix A. Mathematical derivations

A.1 Derivation of import shock

For all the simulations in which we assume an exogenous price shock to a single industry, we also assume that there is an equivalent shock to the import price of such industry. That is, if there is an exogenous price increase ΔP_X, then we assume an equivalent import price shock, ΔP_M. We refer to this as the non-arbitrage assumption, meaning that the shock does not generate a difference between the domestic and the international price of goods. The next issue is to explain how ΔP_M impactc the costs of industries.

Consider A_M, which is the direct import requirements matrix. Its element a_{ij} represents how much imports of industry j are necessary to produce a unit of sector i. Vector m, the share of imported inputs in gross output, is equal to the sum of the columns of A_M.

Now assume there is a 10 percent increase in the price of imported good 1 (the column-vector ΔP_M will have a zero for all prices that remain constant). This means that every sector will pay 10 percent more for its imports of good 1. We can represent this last proposition by multiplying the first row of matrix A_M by 1.1. Hence, when we add the columns of this modified A_M, we will get a new vector Δm, which represents the new share of imported inputs in gross output that follows from an import price shock to good 1. As we said before, all our simulations with exogenous price shocks implement the assumption that $\Delta P_X = \Delta P_M$, which just means that the price increase is the same for the domestically produced as for the imported good.

A.2 Derivation of price change equation with exogenous sectors

Equation (6) shows how the price of all endogenous sectors change when there is an exogenous price shock to one or more sectors in the economy, which impacts both their domestic and imported price by the same amount. The derivation is identical to Weber et. al (2024), which is itself based on Valadkhani and Mitchell (2002).

Equation (4) can be expressed in the following way:

$$\begin{bmatrix} P_X \\ P_E \end{bmatrix} = \begin{bmatrix} A'_{XX} & A'_{EX} \\ A'_{XE} & A'_{EE} \end{bmatrix} \begin{bmatrix} P_X \\ P_E \end{bmatrix} + \begin{bmatrix} v_X \\ v_E \end{bmatrix} + \begin{bmatrix} m_X \\ m_E \end{bmatrix} \qquad \text{(A1)}$$

All the elements of this equation represent partitions or subsets of the original vectors and matrices and . The criterion to divide them is the exogeneity and endogeneity of sectors. Specifically, X represents the set of exogenous sectors, and E that of endogenous sectors. The partition for and is straightforward. For example, if the exogenous sectors are , then , and will be the first two elements of their corresponding original vector. For the partitions of , the first subindex represents the rows and the second the columns, so that, for example, would consist of the first two rows of matrix (the exogenous sectors), and all but the first two columns of matrix (all the endogenous sectors). Then, solving the multiplication in the first term of equation (A1), and focusing exclusively on the bottom element (the prices of endogenous sectors), we get:

$$P_E = A'_{XE}\, P_X + A'_{EE}\, P_E + v_E + m_E \qquad \text{(A2)}$$

Then solving for will retrieve equation (3) in the main text, and then expressing everything in terms of changes results in equation (4). Notice that the term in equation (4) is calculate as we explain in the previous section of the appendix.

Appendix B. Additional tables and figures

Table B.1: Sectoral descriptions

CPA	Description	Price category	Price quality	Period
01	Agriculture	Producer Price Agriculture	very good	2000-2022
02	Forestry	Producer Price Forestry	very good	2000-2022
03	Fishing	Consumer Price	sufficient	2000-2022
05	Coal	Producer Price Industry	good	2010-2022
06	Oil and Gas	Producer Price Industry	very good	2000-2022
07-09	Mining and Quarrying	Producer Price Industry	very good	2000-2022
10-12	Food, Beverages and Tobacco	Producer Price Industry	very good	2000-2022
13-15	Textiles	Producer Price Industry	very good	2000-2022
16	Wood	Producer Price Industry	very good	2000-2022
17	Paper	Producer Price Industry	very good	2000-2022
18	Printing	Producer Price Industry	very good	2000-2022
19	Coke and Petroleum Products	Producer Price Industry	very good	2000-2022
20	Chemicals	Producer Price Industry	very good	2000-2022
21	Pharmaceutical Products	Producer Price Industry	very good	2000-2022
22	Plastics and Rubber	Producer Price Industry	very good	2000-2022
23.1	Glass	Producer Price Industry	very good	2000-2022
23.2-23.9	Ceramics	Producer Price Industry	very good	2000-2022

24.1-24.3	Primary Metals	Producer Price Industry	very good	2000-2022
24.4	Basic Metals	Producer Price Industry	very good	2000-2022
24.5	Foundry Products	Producer Price Industry	very good	2000-2022
25	Fabricated Metal Products	Producer Price Industry	very good	2000-2022
26	Computers and Electronics	Producer Price Industry	very good	2000-2022
27	Electrical Equipment	Producer Price Industry	very good	2000-2022
28	Machinery	Producer Price Industry	very good	2000-2022
29	Motor Vehicles	Producer Price Industry	very good	2000-2022
30	Other Transport Equipment	Producer Price Industry	very good	2000-2022
31-32	Furniture	Producer Price Industry	very good	2000-2022
33	Repair of Machinery	Producer Price Industry	good	2010-2022
35.1, 35.3	Electricity, Heating and Cooling	Producer Price Industry	good	2010-2022
35.2	Manufactured Gas	Producer Price Industry	very good	2000-2022
36	Water	Producer Price Industry	very good	2000-2022
37-39	Sewerage Services	Calculated based on Producer Price Services	sufficient	2000-2023
41-42	Building and Underground Construction	Calculated based on Construction Industry Price	sufficient	2000-2022
43	Construction	Calculated based on Construction Industry Price	sufficient	2000-2022
45	Motor Vehicle Dealers	Retail Price	very good	2000-2022
46	Wholesale Trade	Wholesale Price	very good	2000-2022
47	Retail Trade	Retail Price	very good	2000-2022

49	Land Transport	Producer Price Services	very good	2006-2022
50	Water Transport	Producer Price Services	very good	2006-2022
51	Air Transport	Producer Price Services	sufficient	2015-2022
52	Warehousing	Producer Price Services	very good	2006-2022
53	Postal Services	Producer Price Services	very good	2006-2022
I	Accommodation and Food Services	Consumer Price	sufficient	2000-2022
J	Information Services	Producer Price Services	very good	2006-2022
K	Finance and Insurance	Consumer Price	sufficient	2000-2022
L	Real Estate Services	House Price Index	sufficient	2005-2022
M	Freelance and Other Services	Producer Price Services	very good	2006-2022
N	Other Economic Services	Producer Price Services	very good	2006-2022
O	Public Administration Services	Calculated based on Producer Price Services	sufficient	2000-2023
P	Education Services	Consumer Price	sufficient	2000-2022
Q	Health Care and Social Services	Consumer Price	sufficient	2000-2022
R-01	Other Personal Services	Calculated based on Consumer Price	sufficient	2000-2023
PRIVAT HH	Services of Households as Employers	Calculated based on Producer Price Services	sufficient	2000-2023

Notes: The statistical classification of products by activity (CPA) is the classification of products at the EU level. The price category summarizes the subcategories from which the prices are sourced. If no matching price data was available for a sector, we calculated prices for that sector using weighted averages of prices from other sectors. The price quality reflects the author's assessment of data accuracy in matching the input-output table with the price data. Generally, price data's quality is high when original data directly matches input-output sectors without further adjustments. Data spanning from 2000 to 2022 for industrial products and from 2006 to 2022 for producer prices in services is considered very good. Shorter time frames indicate good quality, while individually calculated or non-producer prices are considered sufficient. Whenever only monthly price data is available it is converted into quarterly data by averaging.

Table B.2: Annual inflation impact across different shockflation scenarios

CPA	Description	Period of price change	Yearly price change (%)	CPI impact model i	CPI impact model ii	CPI impact model iii	CPI impact model i, σ=0.524	CPI impact model i, σ=0.04	Rank forward linkages	Weight in CPI	Rank CPI impact
01	Agriculture	2000-2019	9.97	0.63	0.65	0.73	-0.35	0.52	30	0.03	3
		2021 Q3 - 2022 Q3	36.14	2.30	2.34	2.66	0.91	2.13	30	0.03	4
02	Forestry	2000-2019	8.92	0.02	0.02	0.02	-0.01	0.01	41	0.00	38
		2021 Q3 - 2022 Q3	23.45	0.04	0.05	0.06	0.01	0.04	41	0.00	43
03	Fishing	2000-2019	1.51	0.00	0.00	0.00	-0.01	0.00	43	0.00	53
		2021 Q3 - 2022 Q3	13.02	0.01	0.01	0.01	0.00	0.01	43	0.00	51
05	Coal	2000-2019	3.93	0.01	0.01	0.02	-0.02	0.01	49	0.00	45
		2021 Q3 - 2022 Q3	-5.09	-0.01	-0.02	-0.02	-0.04	-0.02	49	0.00	53
06	Oil and Gas	2000-2019	21.35	0.88	0.93	1.01	0.87	0.88	13	0.01	1
		2021 Q3 - 2022 Q3	204.61	8.41	8.91	9.70	8.37	8.41	13	0.01	1
07-09	Mining and Quarrying	2000-2019	1.60	0.01	0.01	0.01	-0.10	-0.01	19	0.00	46
		2021 Q3 - 2022 Q3	13.97	0.05	0.06	0.06	-0.07	0.04	19	0.00	41

10-12	Food, Beverages and Tobacco	2000-2019	2.76	0.40	0.41	0.50	0.15	0.38	31	0.14	7
		2021 Q3 - 2022 Q3	20.42	2.99	3.02	3.68	2.66	2.95	31	0.14	3
13-15	Textiles	2000-2019	1.08	0.06	0.06	0.05	0.03	0.05	37	0.05	25
		2021 Q3 - 2022 Q3	8.53	0.45	0.45	0.39	0.42	0.44	37	0.05	14
16	Wood	2000-2019	3.78	0.03	0.03	0.03	-0.07	0.02	33	0.00	32
		2021 Q3 - 2022 Q3	11.61	0.08	0.09	0.10	-0.03	0.07	33	0.00	38
17	Paper	2000-2019	3.19	0.04	0.05	0.06	-0.15	0.02	18	0.01	29
		2021 Q3 - 2022 Q3	32.15	0.45	0.48	0.61	0.16	0.41	18	0.01	12
18	Printing	2000-2019	1.15	0.01	0.01	0.01	-0.12	-0.01	42	0.00	47
		2021 Q3 - 2022 Q3	22.77	0.12	0.14	0.22	-0.05	0.10	42	0.00	30
19	Coke and Petroleum Products	2000-2019	11.21	0.55	0.58	0.70	0.37	0.53	14	0.04	5
		2021 Q3 - 2022 Q3	41.48	2.04	2.15	2.58	1.78	2.01	14	0.04	5
20	Chemicals	2000-2019	3.38	0.12	0.13	0.13	-0.11	0.09	5	0.01	14
		2021 Q3 - 2022 Q3	28.27	0.98	1.08	1.11	0.66	0.94	5	0.01	6

21	Pharma-ceutical Products	2000-2019	1.44	0.02	0.02	0.03	0.02	0.02	40	0.02	36
		2021 Q3 - 2022 Q3	2.48	0.04	0.04	0.05	0.03	0.04	40	0.02	44
22	Plastics and Rubber	2000-2019	1.37	0.03	0.03	0.03	-0.21	0.00	25	0.01	33
		2021 Q3 - 2022 Q3	13.66	0.26	0.29	0.31	-0.03	0.22	25	0.01	22
23.1	Glass	2000-2019	2.93	0.01	0.01	0.02	-0.02	0.01	45	0.00	44
		2021 Q3 - 2022 Q3	26.56	0.10	0.11	0.14	0.05	0.09	45	0.00	35
23.2-23.9	Ceramics	2000-2019	1.78	0.01	0.02	0.02	-0.08	0.00	36	0.00	41
		2021 Q3 - 2022 Q3	17.86	0.12	0.15	0.20	0.01	0.11	36	0.00	29
24.1-24.3	Primary Metals	2000-2019	11.76	0.07	0.08	0.09	-0.03	0.05	6	0.00	19
		2021 Q3 - 2022 Q3	24.07	0.13	0.16	0.18	0.02	0.12	6	0.00	27
24.4	Basic Met-als	2000-2019	13.65	0.05	0.06	0.07	-0.02	0.04	7	0.00	26
		2021 Q3 - 2022 Q3	16.01	0.06	0.07	0.08	-0.01	0.05	7	0.00	40
24.5	Foundry Products	2000-2019	2.51	0.01	0.01	0.01	-0.08	0.00	47	0.00	48
		2021 Q3 - 2022 Q3	16.12	0.04	0.04	0.05	-0.06	0.03	47	0.00	45

25	Fabricated Metal Products	2000-2019	1.70	0.03	0.04	0.05	-0.31	-0.01	15	0.01	30
		2021 Q3 - 2022 Q3	15.38	0.30	0.34	0.41	-0.12	0.25	15	0.01	18
26	Computers and Electronics	2000-2019	3.64	0.10	0.10	0.09	0.00	0.09	29	0.02	16
		2021 Q3 - 2022 Q3	6.82	0.18	0.19	0.17	0.08	0.17	29	0.02	26
27	Electrical Equipment	2000-2019	0.64	0.01	0.01	0.02	-0.09	0.00	26	0.01	42
		2021 Q3 - 2022 Q3	10.61	0.20	0.23	0.26	0.08	0.19	26	0.01	24
28	Machinery	2000-2019	0.57	0.01	0.01	0.01	-0.11	-0.01	23	0.00	51
		2021 Q3 - 2022 Q3	9.36	0.09	0.10	0.11	-0.05	0.07	23	0.00	37
29	Motor Vehicles	2000-2019	0.46	0.02	0.02	0.03	-0.03	0.02	27	0.05	35
		2021 Q3 - 2022 Q3	6.13	0.32	0.32	0.44	0.26	0.31	27	0.05	17
30	Other Transport Equipment	2000-2019	1.09	0.01	0.01	0.01	-0.01	0.00	32	0.00	49
		2021 Q3 - 2022 Q3	4.02	0.02	0.02	0.02	0.00	0.02	32	0.00	47
31-32	Furniture	2000-2019	0.73	0.03	0.03	0.03	0.01	0.03	50	0.04	31
		2021 Q3 - 2022 Q3	10.56	0.45	0.45	0.49	0.42	0.45	50	0.04	13

33	Repair of Machinery	2000-2019	0.37	0.00	0.00	0.00	-0.26	-0.03	20	0.00	52
		2021 Q3 - 2022 Q3	5.57	0.05	0.06	0.07	-0.23	0.02	20	0.00	42
35.1, 35.3	Electricity, Heating and Cooling	2000-2019	5.43	0.23	0.24	0.37	-0.33	0.16	12	0.03	10
		2021 Q3 - 2022 Q3	118.13	4.94	5.27	8.14	3.22	4.68	12	0.03	2
35.2	Manufactured Gas	2000-2019	16.03	0.06	0.07	0.16	-0.11	0.04	34	0.00	22
		2021 Q3 - 2022 Q3	189.16	0.73	0.87	1.93	0.06	0.61	34	0.00	9
36	Water	2000-2019	0.88	0.01	0.01	0.01	-0.04	0.00	51	0.00	50
		2021 Q3 - 2022 Q3	2.99	0.02	0.02	0.03	-0.03	0.01	51	0.00	49
37-39	Sewerage Services	2000-2019	3.24	0.06	0.07	0.10	-0.28	0.02	16	0.01	21
		2021 Q3 - 2022 Q3	5.82	0.11	0.12	0.19	-0.24	0.07	16	0.01	34
41-42	Building and Underground Construction	2000-2019	1.71	0.01	0.02	0.02	-0.22	-0.02	44	0.00	43
		2021 Q3 - 2022 Q3	17.47	0.12	0.16	0.22	-0.18	0.08	44	0.00	32
43	Construction	2000-2019	1.71	0.06	0.08	0.11	-1.03	-0.06	17	0.00	23
		2021 Q3 - 2022 Q3	17.47	0.61	0.80	1.09	-0.77	0.45	17	0.00	10

45	Motor Vehicle Dealers	2000-2019	0.94	0.03	0.03	0.05	-0.28	-0.01	28	0.02	34
		2021 Q3 - 2022 Q3	10.13	0.28	0.29	0.49	-0.08	0.24	28	0.02	20
46	Wholesale Trade	2000-2019	3.34	0.14	0.16	0.30	-1.33	-0.03	8	0.00	12
		2021 Q3 - 2022 Q3	19.43	0.81	0.95	1.74	-1.05	0.59	8	0.00	8
47	Retail Trade	2000-2019	0.86	0.02	0.02	0.08	-0.68	-0.06	22	0.00	37
		2021 Q3 - 2022 Q3	9.34	0.19	0.22	0.91	-0.61	0.10	22	0.00	25
49	Land Transport	2000-2019	7.61	0.26	0.29	0.47	-0.43	0.18	10	0.01	9
		2021 Q3 - 2022 Q3	13.01	0.44	0.49	0.81	-0.31	0.35	10	0.01	15
50	Water Transport	2000-2019	28.08	0.08	0.09	0.16	0.06	0.08	39	0.00	18
		2021 Q3 - 2022 Q3	3.21	0.01	0.01	0.02	-0.01	0.01	39	0.00	52
51	Air Transport	2000-2019	2.17	0.02	0.02	0.02	-0.05	0.01	46	0.00	39
		2021 Q3 - 2022 Q3	16.42	0.12	0.13	0.17	0.04	0.11	46	0.00	31
52	Warehous-ing	2000-2019	15.97	0.44	0.52	0.77	-0.59	0.32	4	0.00	6
		2021 Q3 - 2022 Q3	11.93	0.33	0.39	0.57	-0.64	0.21	4	0.00	16

53	Postal Services	2000-2019	6.68	0.08	0.10	0.18	-0.32	0.04	24	0.00	17
		2021 Q3 - 2022 Q3	5.61	0.07	0.08	0.15	-0.32	0.02	24	0.00	39
I	Accommo-dation and Food Services	2000-2019	0.87	0.05	0.05	0.09	-0.04	0.04	38	0.05	28
		2021 Q3 - 2022 Q3	8.46	0.46	0.48	0.88	0.37	0.45	38	0.05	11
J	Information Services	2000-2019	2.77	0.18	0.20	0.29	-0.66	0.09	3	0.04	11
		2021 Q3 - 2022 Q3	1.29	0.09	0.10	0.13	-0.74	-0.01	3	0.04	36
K	Finance and Insur-ance	2000-2019	1.87	0.13	0.15	0.24	-0.82	0.02	9	0.04	13
		2021 Q3 - 2022 Q3	1.92	0.13	0.15	0.25	-0.82	0.03	9	0.04	28
L	Real Estate Services	2000-2019	2.99	0.64	0.66	1.17	-0.38	0.53	11	0.19	2
		2021 Q3 - 2022 Q3	4.30	0.92	0.95	1.68	-0.12	0.81	11	0.19	7
M	Freelance and Other Services	2000-2019	5.07	0.36	0.44	0.56	-1.68	0.13	1	0.01	8
		2021 Q3 - 2022 Q3	3.52	0.25	0.30	0.39	-1.74	0.03	1	0.01	23
N	Other Economic Services	2000-2019	7.62	0.60	0.70	1.01	-1.25	0.39	2	0.03	4
		2021 Q3 - 2022 Q3	3.49	0.28	0.32	0.46	-1.46	0.08	2	0.03	21

O	Public Adminis-tration Services	2000-2019	3.24	0.06	0.08	0.11	-0.44	0.01	21	0.01	20
		2021 Q3 - 2022 Q3	5.82	0.12	0.14	0.20	-0.41	0.05	21	0.01	33
P	Education Services	2000-2019	7.80	0.12	0.12	0.22	0.00	0.10	48	0.01	15
		2021 Q3 - 2022 Q3	1.98	0.03	0.03	0.06	-0.08	0.02	48	0.01	46
Q	Health Care and Social Services	2000-2019	1.16	0.06	0.06	0.11	0.05	0.06	52	0.04	24
		2021 Q3 - 2022 Q3	5.82	0.29	0.29	0.54	0.28	0.29	52	0.04	19
R-01	Other Personal Services	2000-2019	1.00	0.05	0.05	0.09	-0.15	0.03	35	0.00	27
		2021 Q3 - 2022 Q3	0.31	0.02	0.02	0.03	-0.18	-0.01	35	0.00	50
PRIVAT HH	Services of Households as Employers	2000-2019	3.24	0.01	0.01	0.03	0.01	0.01	53	0.05	40
		2021 Q3 - 2022 Q3	5.20	0.02	0.02	0.04	0.02	0.02	53	0.05	48

Notes: The statistical classification of products by activity (CPA) is the classification of products at the level of the EU. The description gives the corresponding name. The period of price change includes the average price changes per sector between 2000 and 2019 based on the standard deviation of the yearly price changes. The other period gives the yearly sectoral price changes from the third quarter of 2021 to the third quarter of 2022, that is the peak of the energy crisis in Germany. The yearly price change includes each sector's price change in the respective period in percent. Each sector's CPI impact is displayed across models with different passthrough assumptions, that is the baseline model i, model ii with constant profit share, and model ii with constant profit share and constant real wages, as well as with the different elasticities of substitution. In addition, each industry's ranking among the 53 sectors in terms of forward linkages is provided, as is the sectors' ranking in terms of the overall inflation impact for the price shock model i.

Table B. 3: Inflation impact across different carbon price scenarios

Sector	Optimistic scenario	Middle-of-the-road scenario	Pessimistic scenario	Price system
Agriculture	0.00	0.00	0.00	none
Forestry	0.00	0.00	0.00	none
Fishing	0.00	0.00	0.00	none
Coal	0.00	0.00	0.01	ETS1 / ETS2
Oil and Gas	0.02	0.04	0.09	ETS1 / ETS2
Mining and Quarrying	0.00	0.00	0.00	ETS1 / ETS2
Food, Beverages and Tobacco	0.04	0.07	0.12	ETS1 / ETS2
Clothing	0.01	0.02	0.03	ETS1 / ETS2
Wood	0.00	0.00	0.00	ETS1 / ETS2
Paper	0.01	0.01	0.03	ETS1 / ETS2
Printing	0.00	0.00	0.00	ETS1 / ETS2
Coke and Petroleum Products	0.07	0.14	0.31	ETS1 / ETS2
Chemicals	0.01	0.03	0.06	ETS1 / ETS2
Pharmaceutical Products	0.00	0.01	0.01	ETS1 / ETS2
Plastics and Rubber	0.00	0.01	0.01	ETS1 / ETS2
Glass	0.00	0.00	0.01	ETS1
Ceramics	0.00	0.02	0.05	ETS1
Primary Metals	0.00	0.01	0.02	ETS1
Basic Metals	0.00	0.00	0.00	ETS1
Foundry Products	0.00	0.00	0.00	ETS1
Fabricated Metal Products	0.00	0.01	0.01	ETS1 / ETS2

Computers and Electronics	0.00	0.00	0.00	ETS1
Electrical Equipment	0.00	0.01	0.01	ETS1 / ETS2
Machinery	0.00	0.00	0.00	ETS1 / ETS2
Motor Vehicles	0.02	0.02	0.04	ETS1 / ETS2
Other Transport Equipment	0.00	0.00	0.00	ETS1 / ETS2
Furniture	0.01	0.02	0.03	ETS1 / ETS2
Repair of Machinery	0.00	0.00	0.00	ETS1
Electricity, Heating and Cooling	0.12	0.36	0.91	ETS1 / ETS2
Manufactured Gas	0.00	0.01	0.01	ETS1 / ETS2
Water	0.00	0.00	0.00	ETS1 / ETS2
Sewerage Services	0.00	0.00	0.00	ETS1
Building and Underground Cons-truction	0.00	0.00	0.00	ETS1
Construction	0.00	0.00	0.00	ETS1
Motor Vehicle Dealers	0.01	0.01	0.02	ETS2
Wholesale Trade	0.02	0.02	0.03	ETS1 / ETS2
Retail Trade	0.01	0.01	0.02	ETS2
Land Transport	0.38	0.52	0.80	ETS1 /ETS2
Water Transport	0.00	0.00	0.01	ETS1
Air Transport	0.00	0.01	0.01	ETS1
Warehousing	0.01	0.01	0.02	ETS1 / ETS2
Postal Services	0.00	0.01	0.01	ETS2
Accommodation and Food Services	0.02	0.02	0.04	ETS2
Information Services	0.02	0.03	0.05	ETS2
Finance and Insurance	0.02	0.03	0.04	ETS2
Real Estate Services	0.28	0.38	0.58	ETS1 / ETS2
Freelance and Other Services	0.02	0.03	0.04	ETS1 / ETS2
Other Economic Services	0.03	0.04	0.06	ETS1 / ETS2
Public Administration Services	0.00	0.00	0.00	ETS1
Education Services	0.01	0.01	0.01	ETS1 / ETS2

Health Care and Social Services	0.02	0.02	0.04	ETS1 / ETS2
Other Personal Services	0.02	0.02	0.04	ETS2
Services of Households as Employers	0.00	0.00	0.00	none

Notes: The table shows the results for each sector's CPI impact across different carbon pricing models. The most optimistic scenario includes lower bound carbon prices of EUR 95/tCO_2 for the ETS1 sectors, and EUR 210/tCO_2 for the ETS2 sectors, the middle scenario entails carbon prices of EUR 130/tCO_2 for the ETS1 sectors, and EUR 275/tCO_2 for the ETS2 sectors, the most pessimistic scenario is calculated based on upper bound carbon prices of EUR 210 /tCO_2 for the ETS1 sectors and EUR 405/tCO_2 for the ETS2 sectors. The statistical classification of products by activity (CPA) is the classification of products at the level of the EU.

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